AGRICULTURAL ENGINEERING

JANUARY • 1954

In this Issue . . .

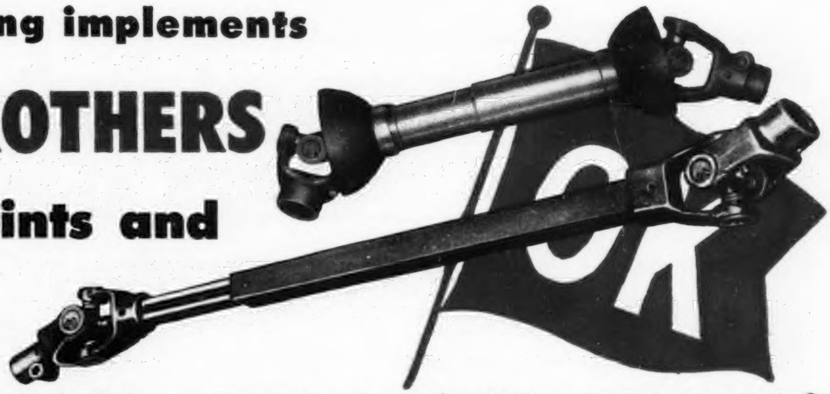
THE JOURNAL OF THE
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

For feed grinding implements

BLOOD BROTHERS

Universal Joints and

Drive Lines



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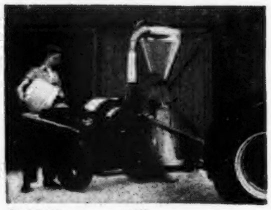
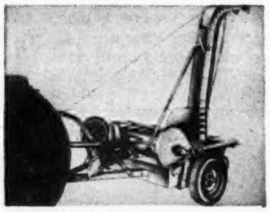


Gehl Hammer Mill



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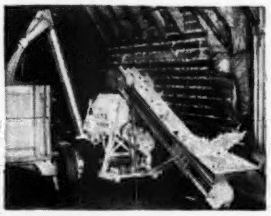
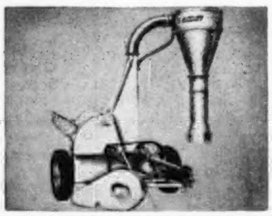


Letz Grinder



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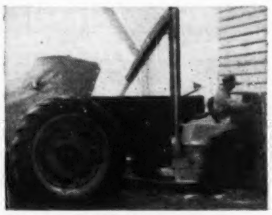

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Note: AGRICULTURAL ENGINEERING is regularly indexed by Engineering Index and by Agricultural Index. Volumes of AGRICULTURAL ENGINEERING, in microfilm form, are available (beginning with Vol. 32, 1951), and inquiries concerning purchase should be directed to University Microfilms, 313 N. First St., Ann Arbor, Michigan.

AGRICULTURAL ENGINEERING is owned and published monthly by the American Society of Agricultural Engineers. The editorial, subscription and advertising departments are at the executive office of the Society, 505 Pleasant St., St. Joseph, Mich. (Telephone: 3-2700).

RAYMOND OLNEY
Editor and Publisher

SUBSCRIPTION PRICE: $4.00 a year, plus an extra postage charge to all countries to which the second-class postage rate does not apply; to ASAE members anywhere, $3.00 a year. Single copies (current), 40 cents each.

POST OFFICE ENTRY: Entered as second-class matter, October 28, 1933, at the post office at Benton Harbor, Michigan, under the Act of August 24, 1912. Additional entry at St. Joseph, Michigan. Acceptance for mailing at the special rate of postage provided for in Section 1103. Act of October 3, 1917, authorized August 11, 1921.

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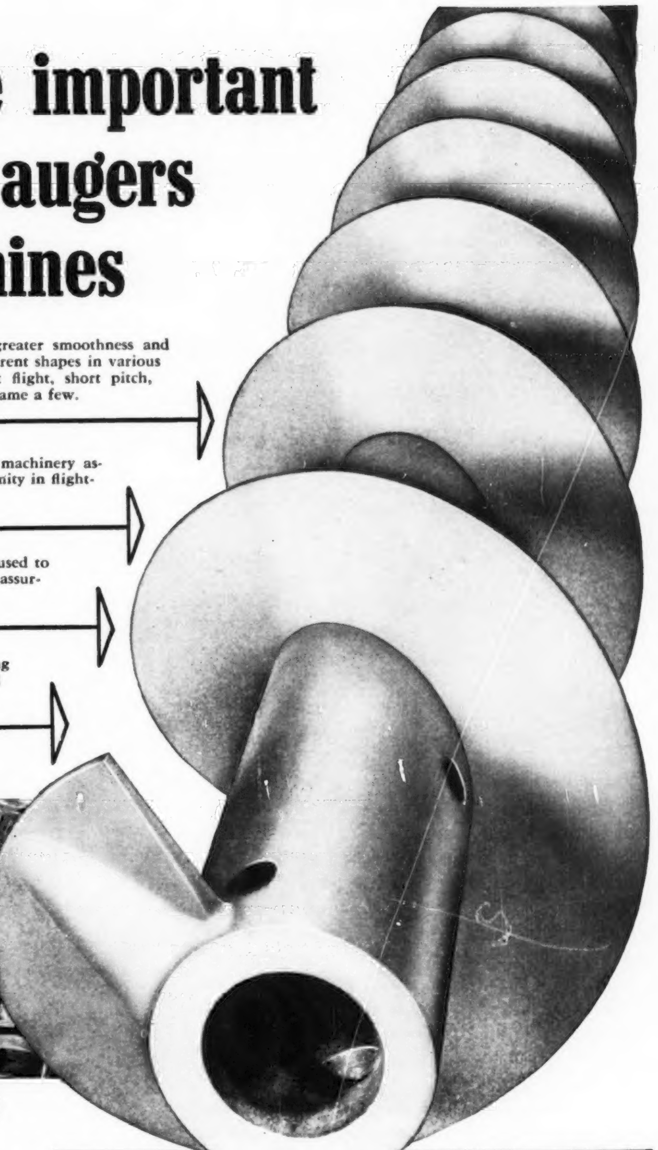

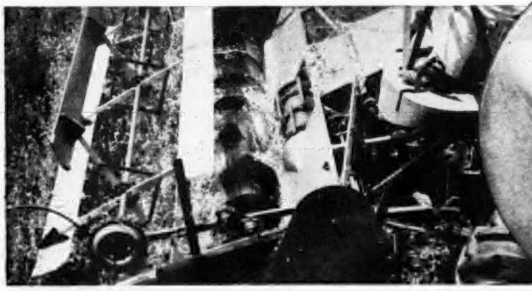

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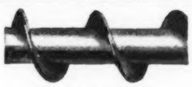

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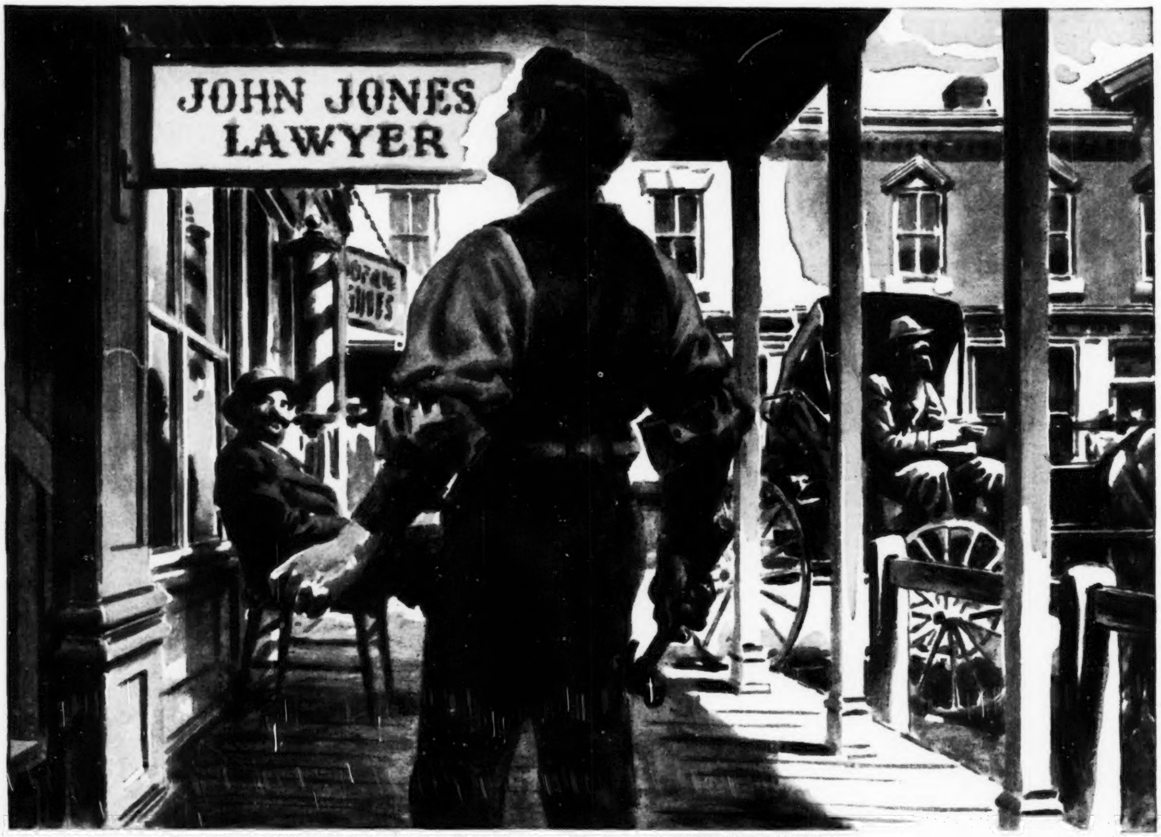
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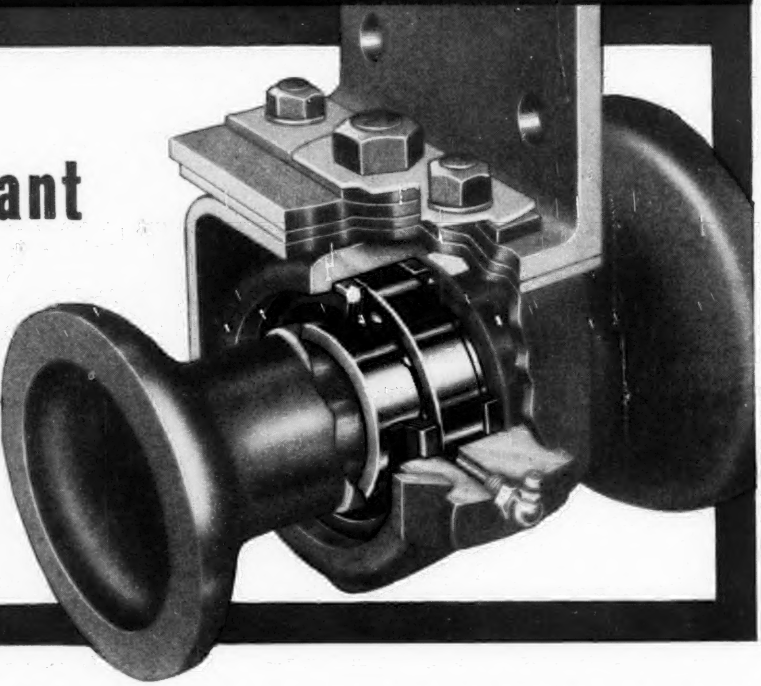

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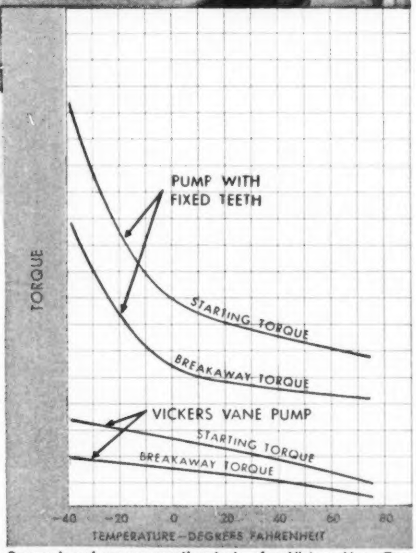
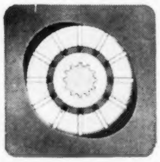
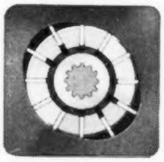


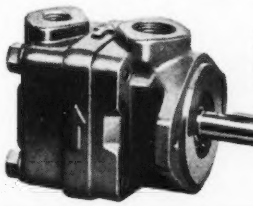
Curves based on comparative tests of a Vickers Vane Type Pump and an equal capacity pump with fixed teeth. Oil used in both was SAE 10W premium grade.



(Left) Schematic diagram of Vickers Balanced Vane Type Pump showing how sliding vanes are retracted at normal engine cranking speeds. No oil is pumped and there is practically no starting load.

(Right) Similar diagram of Vickers pump showing how pump vanes are extended when engine is running. Pumping then begins and continues at all engine speeds.





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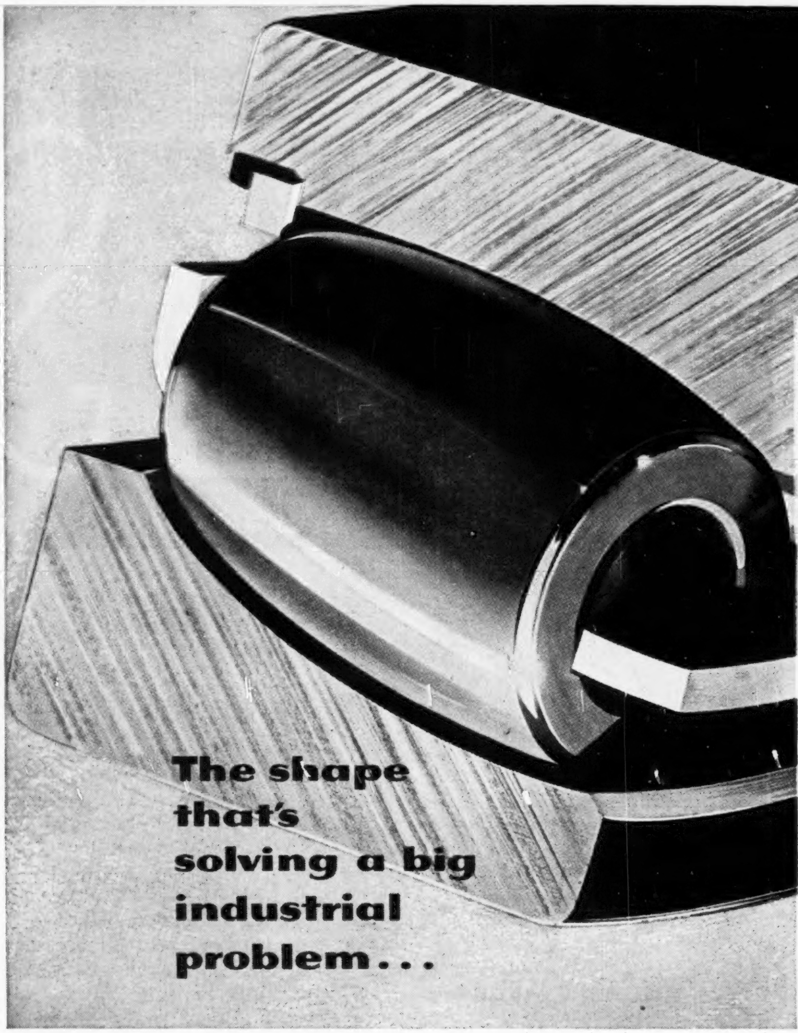

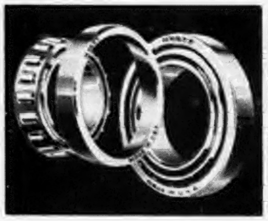

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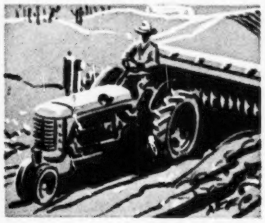

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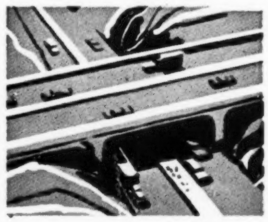

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AGRICULTURAL ENGINEERING

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Power Requirements of Combine Drives

D. E. Burrough
ASSOC. MEMBER ASAE

DURING the harvest seasons of 1951 and 1952, tests were conducted by the agricultural engineering department of Purdue University to determine the power and torque requirements of the individual drives of a combine. Although many observations were made in obtaining the data, there was not sufficient duplication and variation in conditions to establish definite relationships. It is felt, however, that the characteristics observed during these tests might be of assistance to those associated with combine design.

Two machines were used in obtaining the data. One combine was self-propelled and employed crossover separation. This machine was equipped with an 8-ft cutter bar having a 4-in gather. The cylinder used was the flail or rub-bar type. This machine was used for the tests conducted in 1951.

The one used for the 1952 tests was a pull-type combine and was equipped with an auxiliary engine. This machine employed a rasp-bar cylinder and straight-through separation. The width of cut was 6 ft 8 in with a 4-in gather.

This paper was presented at the winter meeting of the American Society of Agricultural Engineers at Chicago, Ill., December, 1952, as a contribution of the Power and Machinery Division. Approved by the Director as Journal Paper No. 746 of Purdue University Agricultural Experiment Station.

The author—D. E. BURROUGH—formerly assistant professor of agricultural engineering, Purdue University, and now special engineer, Bettendorf Works, J. I. Case Co.

Acknowledgment: The author expresses thanks to the following individuals and companies for making possible the study reported in this paper: C. J. Scranton and R. L. Worrell of Allis-Chalmers Mfg. Co., for providing a self-propelled combine for testing; The Massey-Harris Co., for the loan of the pull-type combine; R. P. Harbage of the New Holland Machine Co., formerly an instructor in agricultural engineering at Purdue University, from whose master's thesis the data on the self-propelled combine was obtained; J. A. Graham, graduate student in farm power and machinery, who ably assisted during the 1952 tests, and N. E. Winters for preparing the curves accompanying this paper.

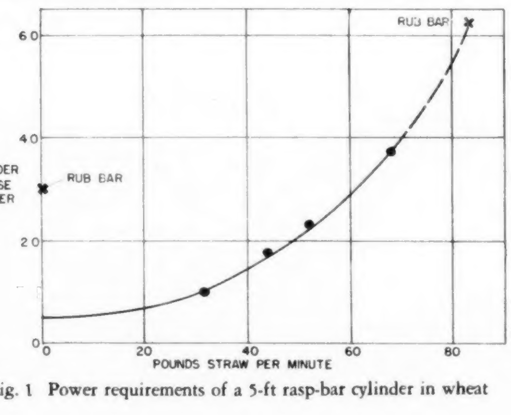

Fig. 1 Power requirements of a 5-ft rasp-bar cylinder in wheat

Most of the tests on the self-propelled combine were conducted to determine the maximum conditions which the machine would be expected to encounter, whereas the tests on the pull-type machine were conducted to determine the change in power requirement with increasing rate. For this reason only the power requirements of the drives in the pull-type combine will be discussed in detail with reference to the self-propelled combine tests for comparison.

TEST PROCEDURE

The field test strips were 100 ft in length and were selected in areas where the crop was uniform. The amount of straw in the various strips was determined after each run in the 1952 tests, while an average straw weight was determined in the 1951 tests. The rate was determined by timing the machine through the test area.

POWER REQUIREMENTS

Cylinder

Wheat. The cylinder power requirements represent approximately 50 percent of the total combine power when operating under normal conditions. The cylinder is very responsive to the rate of material flow. In open-sowed crops the power requirements increase rapidly as the rate of flow increases. This does not appear to be the case in rowed crops such as soybeans. Fig. 1 shows the power required by a 5-ft rasp-bar cylinder in wheat. The friction power was 0.5 hp at a cylinder speed of 1000 rpm. At a rate of 30 lb per min flow of threshed straw the power had increased to 1 hp. When the rate was 60 lb per min, the power required was 2.9 hp. This indicates a rapidly increasing power requirement as the speed of travel is increased, or rather as the rate of flow is increased. In other words, if the cutter bar were increased from 5 ft to 7 ft and all other factors

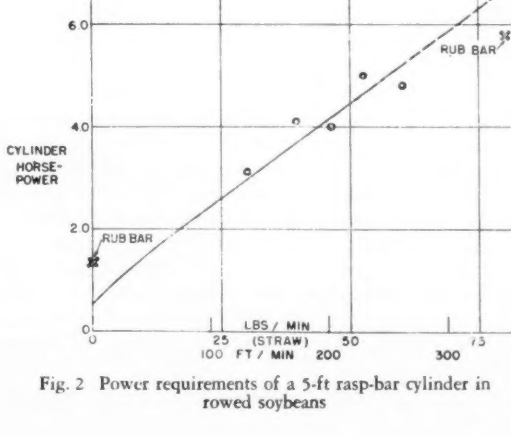

Fig. 2 Power requirements of a 5-ft rasp-bar cylinder in rowed soybeans

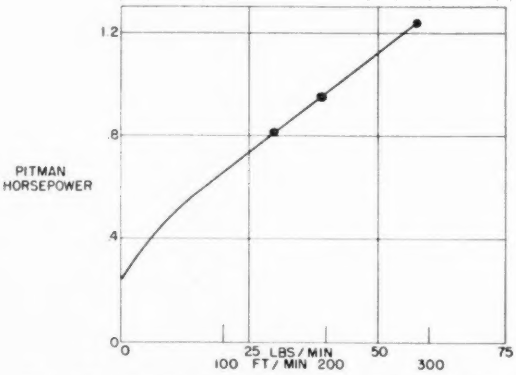

Fig. 3 Pitman horsepower of a 6-ft 8-in cut in soybeans

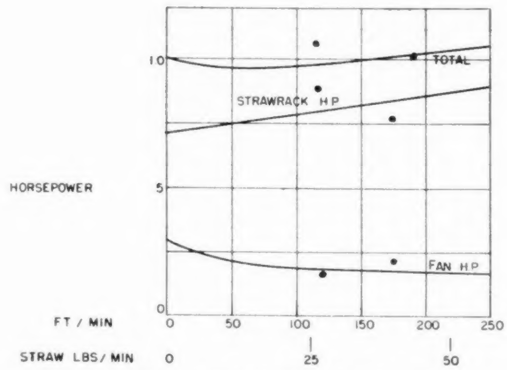

Fig. 4 Separation horsepower in rowed soybeans

kept the same, the power required would not increase as the ratio of cut but would double. This relationship needs to be considered when the cutter bar length is to be increased without appropriate changes in the cylinder.

The rub-bar cylinder required considerably more power than the rasp-bar cylinder at no load condition. The friction power of this unit was 3 hp at 1400 rpm. This appears to put the rub-bar cylinder at a disadvantage in terms of power. However, at the higher rates of flow the power required by this cylinder falls almost on the extension of the curve formed by the points plotted for the rasp-bar cylinder. Actually this cylinder behaves much like a fan and probably at least 2.5 of the 3 hp required at no-load condition can be attributed to windage. As the rate of flow of unthreshed grain increases, the amount of air moved decreases with a corresponding decrease in power. Just what the power requirements of the cylinder are between the two points plotted is entirely a matter for conjecture since the data is not available for any intermediate points.

Soybeans. The power requirements of the rasp-bar cylinder in rowed soybeans has considerably different characteristics than those exhibited in wheat. Fig. 2 shows the power requirements as the rate of travel is increased with a corresponding rate of material flow. Although the power required for the cylinder is higher in beans than in wheat at the same rate of material flow, the curve characteristics is more nearly linear. This dissimilarity must be due to (1) the difference in the material, (2) the way it is fed into the machine, or (3) the initial concave-cylinder bar clearance. In open-sowed crops such as wheat, the material covers the complete width of cylinder and the only way an increase in the amount of material flow may be accomplished is by an increase in the thickness of the material passing through. When this occurs there is more work done in compressing the material as it passes through the concave-cylinder bar clearance thereby causing a disproportionate power increase. On the other hand, the rowed material is fed into the machine in two distinct bands. As the rate is increased in this case, the material tends to spread laterally since it has room on either side. This eliminates the additional work necessary for compressing the material and allows distribution over a larger surface of the cylinder giving a power requirement more nearly proportional to the rate of material flow into the cylinder.

The rub-bar cylinder again required more power under no load condition. The measured value was 1.3 hp and is designated in Fig. 2. The lower no-load horsepower requirement is due to a lower cylinder speed and less power used in moving air. At the higher rates the difference in power requirements seems to be less. By extending the power curve of the rasp-bar cylinder to the 80 lb-per-min rate which corresponds to the lowest measured rate on the rub-bar cylinder, the power indicated for the rasp-bar cylinder is approximately 0.8 hp greater.

Maximum Conditions. The maximum load existing over one second was 10.0 hp for the rasp-bar cylinder in wheat, whereas the maximum load for the rub-bar cylinder was 16.8 hp in open-sowed soybeans. The power available from the engine at the time the slugging occurred was 16 hp for the rasp-bar cylinder and 22 hp for the rub-bar cylinder. This indicates that as the power available is increased, as in the self-propelled units, the possibility of increasing the maximum overload conditions becomes an important factor.

Cutter Bar

Wheat. The cutter-bar power was approximately 0.16 hp at no-load condition and increased linearly in wheat to 0.62 hp at a rate of 50 lb per min. The width of cut was 6 ft 8 in with a 4-in gather. The acceleration forces were

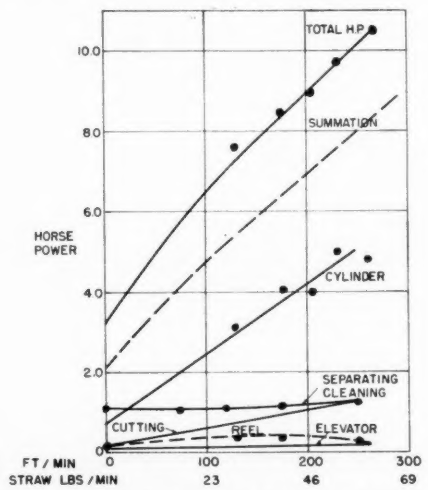

Fig. 5 Power distribution for a 7-ft combine in soybeans

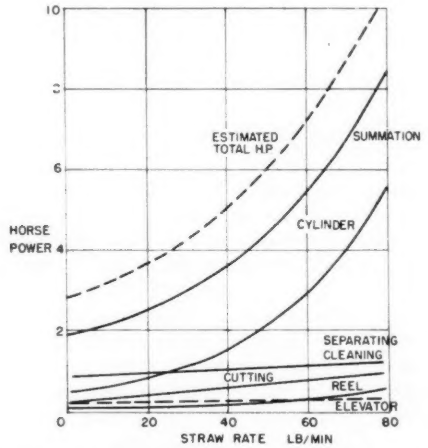

Fig. 6 Power distribution for a 7-ft combine in wheat

not changed greatly when the cutting load was being recorded; this, however, was not the case in soybeans.

Soybeans. The cutter-bar power represented almost one-tenth of the total power required by the combine throughout the tests. Fig. 3 shows the power required by the cutter bar at varying rates of travel. The power requirements increased almost linearly as the rate of travel increased. The maximum torque recorded over one second interval was 240 lb-in, giving a required power of 1.37 hp. The peak torque recorded was 800 lb-in with an amplitude of 960 lb-in at a frequency of 12 cycles per second and a crank speed of 360 rpm.

The maximum axial forces in the pitman under no-load condition which were due to the acceleration of the sickle were 230 lb compressive and tensile. Under maximum load conditions these forces were increased to 394 lb compressive and tensile and occurred at the end of each stroke. The maximum cutting force was 264 lb which gave a momentary power of 4.4 hp twice during each cycle. The higher acceleration forces under load may be explained by the momentary slow-down of the drive pulley during the cutting load due to slippage and elongation of the belt. This condition caused additional acceleration forces due to the variation in the speed of the driver at the end of each stroke.

Tests conducted while cutting a dense growth of grass at 4 mph indicated a maximum cutting load of 296 lb, acceleration forces of 394 lb and a mean power requirement of 1.6 hp.

Reel

The reel drive consumed little of the power required for the machine. Under no-load condition the power requirements were 0.11 hp. In wheat the maximum average power was 0.31 hp whereas in beans it was 0.35 hp. The peak torsional load occurred in the soybean tests and was 283 lb-in. This loading repeated itself each time a batt passed the cutter bar. In terms of force on the batts of the reel, this loading would represent a force of 94 lb. As the rate of travel increased in the soybean tests, the power required by the reel decreased. This could be expected since the reel speed was constant, and therefore as the ground speed increased the peripheral speed of the reel approached the travel speed.

Separation and Cleaning

Fan. Although the total power requirements of the fan in each machine did not have much bearing on the total load requirements, their characteristics are interesting. One machine employed shutters to regulate the amount of air and a wind board for directing its flow. The no-load power for this unit was 0.3 hp. Under load conditions the power dropped to approximately 0.18 hp in soybeans. When the machine was set for wheat, the no-load requirement was 0.2 hp, and decreased to 0.16 when the cleaning shoe was loaded. This may be explained by the characteristics of this type of fan; that is, high power requirements under low static pressures and a decrease in power as the static pressure is increased. The material passing over the cleaning shoe acted as a valve causing a build-up in static pressure with a resulting decrease in power requirements. Fig. 4 shows the variation in power for separating and cleaning soybeans.

The fan on the other machine was not responsive to load since the direction and amount of air was regulated by a valve on the outlet side of the fan housing. This arrangement kept a higher static pressure in the fan housing than that created by the material passing over the shoe.

Straw Rack

The amount of material passing through the machine had very little effect on the power requirements of the rack. The maximum power required by the straw rack of the pull-type combine was only 0.9 hp in soybeans. Although this is a small portion of the total power requirements, the effect of the straw rack is transmitted throughout the rear portion of the machine. Due to the acceleration forces set up by the reciprocating motion of the rack, momentary torsional loads as high as 280 lb-in positive and 120 lb-in

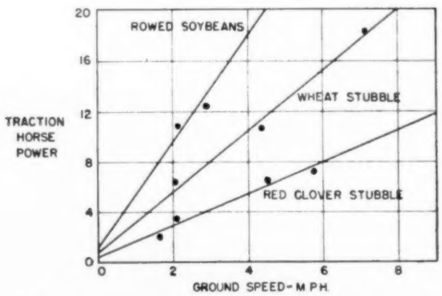

Fig. 7 Traction horsepower vs. ground speed

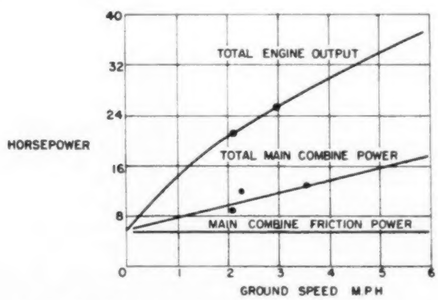

Fig. 8 Power distribution of a self-propelled combine harvesting soybeans

negative with a frequency equal to twice the rack speed are evident.

These loads are cyclic in nature and should be considered when designing any shaft subjected to them. The addition of a unit having appreciable flywheel characteristics on one of the machines reduced the amplitude of the fluctuations in the fan shaft from 415 lb-in to 215 lb-in.

POWER DISTRIBUTION

Soybeans

The power distribution for the pull-type machine is shown in Fig. 5. The values plotted represent the average power requirements of the various drives as the rate of material flow or ground speed increases. The dashed curve represents the summation of the power requirements of the various components. The total measured power required from the engine falls above this curve by approximately 1.0 hp at the low rates and 2 hp at the high rates. This represents the friction loss of the machine that was not recorded by the component measurements. These losses due to friction occurred in the various power transmission devices such as chains, belts and gears. What percent of the total loss can be attributed to the various types of drives cannot be determined from the test data. The efficiency appears to increase as the load increases and is approximately 80 percent at the higher rates. Although the drive layout for this machine appeared to be very satisfactory, the portion of the horsepower attributed to friction was considerable. Further work is needed to study the efficiency of various types of drives used in farm machines. There was not sufficient data to make a similar comparison on the self-propelled combine.

The cylinder requirements represented approximately 50 percent of the total power required at the higher rates and 45 percent at intermediate rates. Under maximum overload conditions the cylinder power requirements almost doubled while those of the other parts of the machine remained almost constant. This condition indicated that the maximum power required from the engine would be almost 15 hp which was near the maximum of that recorded over any definite period.

The cutting mechanism required approximately 10 percent of the total at the higher and also at the intermediate rates. Tests in severe cutting conditions did not indicate a rapid increase in the power requirements as in the cylinder.

The combined separating and cleaning-power requirements are relatively constant and did not increase appreciably as the rate of material processed was increased. Even though the average power requirements are low the reciprocating motion of the rack induces high momentary forces and torsional loads.

Wheat

The power distribution in wheat is considerably different from that in beans. This difference is primarily due to the different characteristics exhibited by the cylinder. The power distribution curve is shown in Fig. 6. Due to instrumentation difficulties the total power supplied by the engine was not determined. The total power curve was plotted on the basis that the frictional loss would be similar in both wheat and soybean harvest.

All components of the machine had the same characteristics in wheat as in soybeans except the cylinder and the pitman. The cylinder power increased rapidly as the rate of flow increased. At intermediate rates its requirements represented only 27 percent of the total while at the higher rate it was 47 percent and increased rapidly. The pitman power increased more rapidly when operating in beans than in wheat but did not show any trend toward unusually high power requirements at the higher rates.

Traction Drive

The power required by the traction drive of the self-propelled combine was determined for the ground conditions encountered during the tests. The gross weight of the machine was approximately 6600 lb with 5000 lb on the traction tires and 1600 lb on the 6.00 x 16 tires. The power requirements for the traction drive in wheat stubble, red clover stubble, and rowed soybeans are shown in Fig. 7. The ground conditions during these tests were optimum. The machine was equipped with 16 x 16 tires when operating on wheat stubble and red clover stubble. These were changed to 10 x 24 tires in rowed soybeans. Probably the 16 x 16 tires would have lowered the power requirements slightly if they had been on the machine at the time of the tests in soybean stubble. In ground conditions comparable with plowed open-sowed bean ground the 16 x 16 tires showed a saving over the 10 x 24 tires of 1.7 hp at 2.4 mph. The power distribution between the main combine drive and traction drive when harvesting soybeans is shown in Fig. 8.

SUMMARY

The results of the tests indicate the following characteristics:

1 The cylinder is very susceptible to loading and in wheat its power consumption increases much more rapidly than the increase in material flow.

2 The cutter-bar load is a maximum in soybeans. However, its load increases linearly both in wheat and soybeans.

3 The power consumed by the separating and cleaning components is not affected by the material flow and is more nearly representative of the friction power required to operate the mechanism.

4 The forces due to the reciprocating action of the straw rack causes peak torsional loads many times the average load conditions.

5 The friction losses due to the various drive mediums vary from 30 percent of the total power required at no-load condition down to 20 percent at the maximum conditions.

6 The traction requires as much power as the main combine drive when operating in bean ground on level land and could easily require considerably more in less favorable conditions.

More Important Than Cotton Gin

THE question of what engineering can do for the country, for its economics over everything else, isn't understood. For instance, we think of Eli Whitney as being the man who invented the cotton gin. But one of the things he did that is of a great deal more importance than the cotton gin was the making of the individual tools to make a single piece or do a single operation upon a piece, which is the basis of our mass production. — Chas F. Kettering in *Mechanical Engineering* for December, 1953.

Economic Analysis of Farm Dairy Buildings

Deane G. Carter and R. N. Van Arsdall
FELLOW ASAE

FARM buildings can make important contributions to the economy and efficiency of farming operations if they provide facilities to reduce labor, protect or improve the quality of products, or cut down on annual overhead costs. But unless adequate attention is given to planning and design, farm structures may burden the owner with a high investment, an inflexible arrangement, and barriers to efficient operation.

This close tie-up between buildings and equipment with problems of economics and management is frequently evident in economic studies. A case in point is a current report on the economic and functional characteristics of farm dairy buildings, which reveals or implies deficiencies in buildings and equipment. It also indicates methods and practices that should be embodied in designs, and deals with costs and functional values of particular interest to engineers. For these reasons, the report* is condensed in this paper, insofar as the findings pertain directly to engineering interest and offer guidance in the application of design.

A field study and analysis was made of dairy operations on 350 Illinois farms in the two principal milksheds that serve the Chicago and St. Louis markets. The farms averaged about 200 acres in size. Herds consisted of from 12 to 120 dairy-animal units with averages of 32 in the Chicago area and 23 in the St. Louis area.

Cows in milk comprised about 70 percent of the total dairy-animal units. Stanchion, or stall, barns were used on 294 farms; modifications of loose-housing systems were found on 56 farms. Most farmers produced good quality milk; two-thirds were on the Grade A market. Farm account records were available in addition to the data obtained by farm visits. Data on inventory, operations, income, and costs were based on or adjusted to 1947.

This paper was prepared expressly for AGRICULTURAL ENGINEERING.

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*R. N. Van Arsdall, D. B. Ibach and Thayer Cleaver, "Economic and Functional Characteristics of Farm Dairy Buildings," Agr. Exp. Sta. Bul. 570 (1953). Results of cooperative research by the Illinois Agricultural Experiment Station and the U.S. Dept. of Agriculture.

It should be noted that the records reflected existing conditions on these farms. Most of the buildings were from 40 to 70 years old. They had been built when the farms produced mostly grain and meat animals. Relatively few new buildings or extensive alteration of old buildings had been made with the shift to dairying. Most barns had loft storage for hay and inflexible stall arrangements. They lacked many features that are now generally recommended.

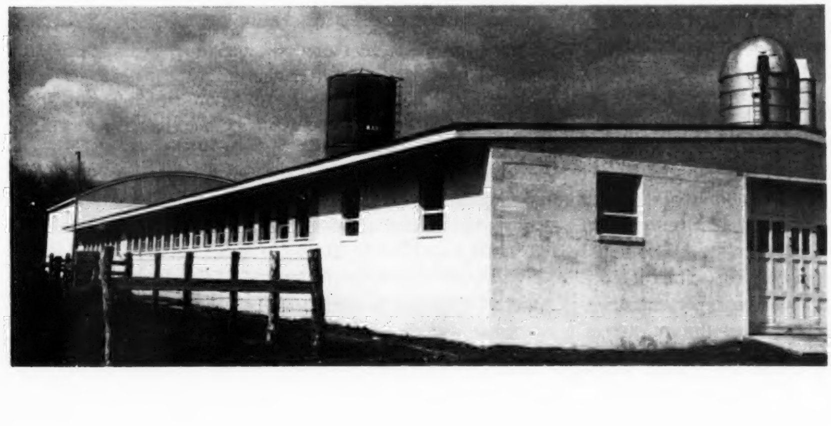
DAIRY BUILDING INVESTMENTS

In the analysis, current inventory values were used in computations. Thus they reflected a lower investment, on the average, than would prevail with newer structures of the same type. For example, the investment per farm in dairy building averaged $3,046 where the structures were depreciated to 40 percent or less of their reproduction cost value. For buildings of medium age with between 41 and 65 percent of value remaining, the average dairy building inventory was $4,579. Newer buildings with more than 65 percent value left in them were inventoried at $8,458 per farm.

These differences are not a reflection of advancing costs; rather they represent the current (depreciated) investment in dairy buildings. To reproduce them at 1947 costs would have required approximately $10,000 per farm. Structures chargeable to dairying represented about 10 percent of the entire farm investment. This was about six-tenths of the service-building inventory on the 350 farms. In general, about one-half the dairy enterprise investment was in dairy buildings.

Based on a comparison with the investment in animals, the average replacement of buildings would have required $372 and $350, respectively, in the Chicago and St. Louis areas for each $100 valuation of dairy stock. The actual range of building inventories was from $50 to $800 per $100 invested in dairy stock, but in 60 percent of the cases it was from $100 to $300 for each $100 worth of animals.

Building values per dairy-animal unit, averaging $375, varied only slightly with the size of the herd. About one-tenth of the variations in investment between large and small herds was attributable to the size of enterprise. The lack of economy to scale is probably due to the many cases where old buildings had been adapted for dairying. A var-



Trends in stall barn design are toward one-story structures, ground-level hay storage, control of environment, and arrangement and equipment for efficiency of operation. Thermopane insulating glass was used in the south-exposure windows in this barn

A loose-housing arrangement for farm dairying that features a combination of milkhouse and milking room with elevated stalls, an open-front shelter shed, and an old barn remodeled for storage and feeding hay

iation in investment according to size of herd was observed in only a limited number of cases where the farms had small or medium-sized herds, typical proportion of producing cows, and neither crowding nor wasted space.

ANNUAL DAIRY BUILDING COSTS

The study revealed that annual costs of dairy buildings averaged about $26 per animal unit, $25.87 for the Chicago area and $26.74 in the St. Louis milkshed. They included depreciation and interest on undepreciated value which, plus prorated taxes and insurance, accounted for about 80 percent of the amount, while other cash outlay for repair and maintenance made up 20 percent of the total. These calculated costs were approximately 10 percent of the yearly cost of the dairy enterprise.

Although annual building costs were slightly lower on farms where gross returns were less than $200 per dairy unit, such low returns appeared to be associated with lack of good dairy management in general. As gross returns rose above $200, there was relatively little increase in building costs per year, per animal unit.

It is apparent that a serious problem is posed in meeting building costs, as well as other expenses of the dairy enterprise. When this study was made, a gross annual return of about $300 per dairy-animal unit was necessary to cover all costs. Only about one-half the farms had such returns. After production costs were met, the net amount for "management" ranged from a loss of $333 to a gain of $203 per dairy-animal unit.

Since the study revealed that approximately 10 percent of the yearly cost of operating the dairy enterprise was charged against buildings it follows that 10 percent of the gross returns from the enterprise should be available to cover the building item. This proportion gave $25.33 in the Chicago area and $27.04 in the St. Louis territory. Thus the returns were just about equal to the $26 average annual cost noted above, with no returns to management.

The solution of building problems must take into account the practical limits of both investment and annual cost. Quality of product, labor efficiency, and functional needs should be considered along with the kind of construction and facilities needed to overcome present deficiencies. These problems are indicated by the results of study on the 350 farms as outlined below.

CHARACTERISTICS OF DAIRY BUILDINGS

A rating scale was devised to measure the functional value of the various features of dairy buildings in comparison with known or generally assumed standards of adequacy. A rating of 1 by the investigator indicated that the item or factor was fully adequate; a 5 rating represented serious deficiency. The rating scale is shown below, together with illustrative data that show the number of farms out of 350 having each of the several ratings as to the conditions of the barn floors.

Rating scale	1.0	1.25-2.0	2.25-3.0	3.25-4.0	4.25-5.0
Floor condition (number of cases)	164	140	17	18	11

Although such a rating scale is somewhat arbitrary, it does serve to compare one farm with another and indicate the conditions encountered. In this study the investigators were given detailed instructions at the start; ratings were reviewed periodically and equalized so far as possible at the end of the field work period. The amount of quantitative data obtained tended to minimize differences due to individual opinion.

The detailed data on functional utility are condensed further in Table 1 to give a general picture of the adequacy of the dairy buildings on 350 farms. It was assumed that ratings of 1 to 2, or the upper 40 percent of the scale, would be typical of generally satisfactory conditions and that ratings from 2.25 to 5 indicate that improvements were needed. As indicated, floors, feed storage, and facilities for getting clean buildings and handling milk were given the higher ratings. The greatest need for improvement was in stalls, external layout, and cleanliness of cows.

Use of space. An obvious deficiency, which probably resulted from the predominance of old buildings, was the lack of coordination between the amount of building space and the size of herd. Space was wasted in haylofts originally intended for loose hay, in barns remodeled for dairy cows, or where large barns were used for small herds. Crowding was due largely to the inflexibility of older barns to accommodate an expanding business. Of 328 cases classified, only 28 had a suitable adjustment to space needs. In 221 cases, or on two-thirds of the farms, either the amount of wasted space or evidence of crowding was "considerable."

Structural Condition. The observed condition of structural parts of dairy barns indicated the following percent-

TABLE 1. PROPORTION OF 350 FARMS HAVING VARIOUS FUNCTIONAL CHARACTERISTICS RATED AS "SATISFACTORY" OR "NEEDING IMPROVEMENT"

Item	Satisfactory (rating of 1-2), percent	Needing improvement (rating of 2.25-5), percent
Stall size	37.5	62.5
Manger and bunks	45.5	54.5
Alleys	45.5	54.5
Ceiling height	64.5	35.5
Young stock space	71.0	29.0
Floor material	90.0	10.0
Floor condition	87.0	13.0
Curb	89.0	11.0
Gutter	36.0	64.0
Walls	77.0	23.0
Gates and doors	47.5	52.5
Protection for concentrates	70.0	30.0
Roughage facilities	78.5	21.5
Water protection	44.0	56.0
Water adequacy	68.0	32.0
External layout	26.0	74.0
Handling cows	85.0	15.0
Handling milk	53.5	46.5
Feed preparation and feeding	59.5	40.5
Cleaning operation	48.0	52.0
Natural lighting	64.5	35.5
Artificial lighting	56.0	44.0
Clean Buildings	73.0	28.0
Clean cows	15.5	84.5
Facilities for washing and sterilizing	91.0	9.0
Water disposal	61.0	39.0
Utensils	91.0	9.0

ages of each item that were counted as "good": Foundations, 71 percent, floors, 75 percent; roofs, 68 percent, and walls, 51 percent. Milkhouse parts were "good" in about 70 percent of the cases.

Features Related to Cleaning. Following are the percentages that were classed as "good" for parts and facilities for adequate cleaning: Stalls, 86; gutters, 90; alleys, 82; lot drainage, 51; equipment for manure removal, 56; and milkhouses, 50.

Water Supply. Most farms had sufficient stock water, but access to the watering place was difficult or inconvenient on 18 percent of the farms; 56 percent had a muddy approach to the supply; 57 percent had inadequate means for protecting stock water from dirt or other foreign material, and 33 percent had no protection against freezing, although some of this group had watering cups in the barn.

Care of Milk. The majority of these farms were producing Grade A milk. This resulted in a relatively high score on facilities. Nevertheless, on the 350 farms, 2 percent were without facilities for washing utensils, 4 percent did not have milkhouses, and 14 percent lacked milk-cooling equipment. On about 40 percent of the farms the milkhouse drain emptied directly outside the foundation.

RELATION OF FUNCTION TO OTHER FACTORS

Altogether, size of herd, age and structural level of buildings, and investment in buildings per dairy animal unit were associated with 38 percent of the variation in the rating of buildings as to their functional adequacy in the Chicago milkshed, and to 46 percent of the variation in the St. Louis area. Most of the remaining variation was attributed to management decisions, particularly with regard to the kind, type, quality, and cost of buildings.

The larger the herd, the higher the functional rating. Twenty percent of the variation in rating was associated with differences in the number of dairy-animal units. Presumably this was because the operator gave a greater relative proportion of his time to dairying.

The newer the building, the higher the functional value. Twelve percent of the variation was associated with age differences. Improvements have been slow in appearing, however. On the farms studied, the average improvement in adequacy was only one score point for each 3½ years reduction in age. The gain may be due largely to the adoption of technological improvements.

High cost did not necessarily increase the usefulness of dairy buildings. The structural quality had little or no apparent effect on function. Only 4 percent of the observed variation was related to differences in the reproduction cost of the buildings.

The farms producing Grade A milk were better than the others in total score, but their improvements were associated more with code requirements than with either production facilities or labor efficiency.

CONCLUSIONS

Farm dairy buildings account for about 10 percent of the entire farm investment on the 350 farms analyzed. They represent approximately one-half of the investment in the dairy enterprise. Current inventory value of dairy buildings averaged $3,046 per farm where the buildings were largely depreciated, $4,575 per farm for medium-valued buildings, and $8,458 per farm where no more than one-third depreciation had occurred; it would take $10,018 per farm to replace them.

Annual costs amounted to about $26 per dairy-animal unit. Eighty percent was depreciation, interest, and prorated insurance and taxes; 20 percent was cash expense for maintenance and repairs. The annual building cost was about 10 percent of production cost for the dairy enterprise. Final calculation showed also that about 10 percent of gross revenue was required to offset dairy building costs.

These data, based on or adjusted to 1947 levels indicate that $26 per animal was the approximate upper limit of annual building cost under the conditions found; otherwise building costs would exceed their proportionate share of gross income. Even under this condition nothing was left as a return to management. Thus it becomes evident that the farmer is faced with at least the following problems:

1 *Obtain higher prices for milk.* This can be ruled out for the majority since they are already on a Grade A market.

2 *Increase the size of the herd.* Generally a higher investment would be called for since the farms with waste building space just about offset those having crowded conditions. The study showed little gain in economy as the herd size increased, presumably because of the kinds and types of buildings being used. But with the use of modern planning methods, it should be possible to decrease the unit cost of buildings as herd size increases.

3 *Improve the productivity of the herd.* While this might be done, the solution is not within the province of the engineer and might not be feasible on some farms.

4 *Make more efficient use of labor.* Labor accounted for 15 percent of production cost on these farms. Design and arrangement to simplify chore work and reduce labor offers a challenging opportunity for important contributions to economy. *(Continued on page 27)*

Economic Feasibility of Supplemental Irrigation

D. B. Krimgold
MEMBER ASAE

IN a short paper published a little over a year ago (1)* the author called attention to the Thornthwaite method of determining time and amount of irrigation. Since that paper was written, I have been engaged in a research project under a contract between The Johns Hopkins University and the U.S. Air Force†. The purpose of this project is to develop methods of estimating soil moisture from readily available climatic data for use in solving military problems in tractionability. Except for the ultimate application of the results, the studies that had to be made were precisely the same as those that would be called for in solving many irrigation problems.

In the first progress report of the Air Force's contract (2), the problem was outlined under three principal investigations:

1 Study of water properties of soils, which included infiltration, water-holding capacity, permeability, and related factors such as porosity, volume weight, etc.

2 Developing a surface runoff factor so that "effective precipitation", that part of precipitation entering the soil, can be estimated from readily available data.

3 Investigation of Thornthwaite's evapotranspiration formula and procedure and their use in estimating soil-moisture depletions.

The work done so far in the three principal investigations has been described in report No. 2 and in five subsequent reports (2). Our efforts were directed almost exclusively to the analysis and interpretation of the vast amount of hydrologic, pedologic, and climatic data that was accumulated in the course of the last three decades, principally in the United States and in the Soviet Union.

In preparing this paper, I have drawn freely on the results of the investigations carried on under the contract with the Air Force. It is my purpose to demonstrate how the concept of evapotranspiration and knowledge gained from our recent work can be used in estimating the economic feasibility of supplemental irrigation.

Supplemental irrigation – irrigation in regions with a good deal of precipitation during the growing season (we shall call them "humid" for short) – is basically different from irrigation in arid regions, where no appreciable precipitation can be expected during the growing season. In arid regions crop production is not possible without irrigation – you either irrigate or you don't farm. In "humid" regions, on the other hand, the need for irrigation is not always self-evident. When prices on farm products are high, the thoughts of forward-looking farmers in the humid regions turn to irrigation. When prices drop or when there are no *visible signs* of drought, the interest in irrigation ebbs. Thus, except for special locations and crops, supplemental irrigation in the United States has had a long history of boom and bust.

The ready market and relatively high prices received by farmers for cattle, milk, and other products and the important developments in sprinkler irrigation equipment, including pumps, pipes, couplers and sprinklers, are largely responsible for the latest boom in supplemental irrigation. But even with this phenomenal increase the total 1949 irrigated acreage east of the Mississippi, not counting citrus irrigation in Florida, was still something of the order of 250,000 acres out of a total of 122,000,000 acres of cropland harvested.

One of the reasons for the pitifully small proportion of irrigated land east of the Mississippi is that we lack a suitable method for assessing the economic feasibility of supplemental irrigation. The farmer who is trying to make up his mind whether or not to invest in an irrigation system; the irrigation equipment manufacturers, distributors and dealers who wish to maintain and expand their business; the banks that do the financing; the public utilities which may be planning to supply the power, and others directly and indirectly interested in supplemental irrigation – all need a reliable estimate of the economic feasibility of supplemental irrigation, as measured by the increase in net return over a period equal to the economic life of the installation. Such returns are determined by increased yields, improved quality, timely marketing, and prices received by farmers in relation to costs of production. We shall confine ourselves to the physical part and shall leave the prices and costs to those better qualified in the field of agricultural economics.

Supplemental irrigation accompanied by adequate plant nutrient and proper cultural practices increases yields, improves quality, and regulates growth and maturity of crops by maintaining an optimum level of soil moisture in the soil and by ameliorating the agroclimate, i.e., the temperature in the root zone and the temperature and humidity in the layer of air near the ground where the plants live.

Existing hydrologic and climatic evidence, if properly analyzed and adequately presented, would show that practically everywhere in the humid region and nearly every year, the level of soil moisture falls short of the optimum necessary to attain maximum crop yields. Furthermore, with proper analysis it can be shown convincingly that the frequency of moisture deficiency in the humid region is such that the return on the investment in supplemental irrigation would compare quite favorably with the return from fertilizer, agricultural machinery, and other modern costly practices which are no longer questioned.

With farming rapidly assuming all the earmarks of modern industry—large efficient units, scientific management, ample initial investment and credit – it seems strange that supplemental irrigation should be much more subject to boom and bust than are machinery and fertilizer. The answer to this puzzle lies largely in that the various attempts made

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This paper was presented at the winter meeting of the American Society of Agricultural Engineers at Chicago, Ill., December, 1953, as a contribution of the Soil and Water Division.

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*Numbers in parentheses refer to the appended references.

†The research reported in this paper has been made possible through support and sponsorship extended by the geophysical research directorate of the Cambridge Field Station, Air Material Command, U.S. Air Force, under Contract No. AF 19 (604)-193. It is published for its technical information only and does not represent recommendations or conclusions of the sponsoring agency.

thus far to demonstrate the continuous need for and continuous benefits from supplemental irrigation have not been successful. They have not been successful because imperfect understanding of the relationship between plants, water, soil, and climate did not permit a clear statement of the problems involved.

The great advances in agricultural hydrology and climatology made during the last three decades in the United States and elsewhere have brought about a radical change in the basic approach to supplemental irrigation. With the new approach based on a more complete understanding of the factors and principles involved, it is possible to set out clearly the physical conditions which must be met to insure financial success or economic feasibility of an irrigation installation in a humid region.

The best way to accomplish this is first to ask ourselves, What is it that we are trying to achieve with supplemental irrigation? The answer is: to obtain maximum crop yields by maintaining an *optimum* moisture content in the root zone. The next question is what constitutes an *optimum* moisture content and what is the root zone?

For many years those concerned with irrigation and with soil moisture have accepted without much question the view that water in the soil is just as readily available to plants when the moisture content is near field capacity as when it is near the wilting coefficient. Considerable experimental evidence has been presented in support of this view. However, the more we have learned about water properties of soils, the harder it has become to accept this thesis. Whether we think in terms of tension or in terms of thickness of the water films, the conclusion is the same. The mobility of soil moisture and, therefore, its availability must increase with the moisture content. Experimental evidence supporting this reasoning has existed for many years but somehow it has been overlooked. M. R. Lewis's results (3) published in 1934 indicated that there is some level of moisture, considerably above the wilting coefficient, below which plant growth is impeded and crop yields are reduced. Bowen (4) in 1938 states: "In actual farming practice it is not advisable to permit the moisture to become depleted to the wilting point, as such a depletion will naturally retard growth. A better practice would be to irrigate at times when there is at least 0.5 in of water available for each foot of depth."

AWARENESS OF OPTIMUM MOISTURE CONTENT

From his own work and from results reported by a number of other investigators, Alptiev (5) concludes that the lower limit of the optimum range of soil moisture is 70 percent of field capacity for clay loams, 50 percent for sandy loams and somewhat less than 50 percent of field capacity for sandy soils. Rode (6) discusses in great detail all the important experimental work on soil moisture — plant relationships done in the Soviet Union, the United States, and elsewhere. From his own investigations and those of Litvinov (7), Kolotova (8), and Kokina (9), and by entirely independent reasoning involving only the physical properties of soils, Rode arrives at the same values for the lower limit of optimum soil moisture as did Alpatiev (5), Ryzhov (10), and Zaitzev (11). Many recent articles in farm magazines and in trade journals indicate, on the part of farmers and practical irrigators, an increasing awareness of what we shall call the optimum moisture content of various soils. All this theoretical and experimental work and these practical observations lead one to the conclusion that "optimum moisture content" is a reality and that for practical purposes its lower limits can be taken as 70 percent of field capacity for fine-textured and 50 percent for coarse-textured soils.

Root zone is a concept which requires some clarification. There are a good many estimates of the root zones of various plants. Davis (12) reports the "depth of rooting of crops in Michigan" under three headings: very shallow, less than 18 in; shallow, 18-36 in; moderately deep, more than 36 in. Tate quoted by Houk (13) reports root zone depths of vegetables "under favorable soil conditions in Arizona" under the following headings: shallow rooted, 0-2 ft; moderately deep-rooted, 0-4 ft; deep-rooted, 0-6 ft. These ranges in depth given by Tate imply variable root zones which are much more realistic. The root zones of all annual crops obviously vary from nearly zero to some depth that depends partly on the crop but principally on the texture and structure of the soil. Studies of root ramification too numerous to quote here all point to the same conclusion, namely, that more than 75 percent of the roots and probably more than 90 percent of the root hairs of most crops are found in the upper 2 ft of the soil.

RELATION BETWEEN ROOTS AND AVAILABLE MOISTURE

Rode (6) has this to say about the relation between roots and available moisture: "We know that water enters the roots through root hairs which have a diameter on the order of 0.01 mm. Only that portion of the soil water that comes in direct contact with the root hairs can be utilized by the plant. But we know that the cross section of soil pores particularily in fine-textured soils is often considerably smaller than that of the root hairs. . . . Obviously the water contained in such pores can be utilized by the root hairs only when this water moves towards them under the influence of some force or other." Houk (13), referring to the Bureau of Reclamation Bulletin No. 2 and to Pillsbury, states that "in a deep sandy loam in Scotts Bluff, Neb., potatoes, oats, and sugar beets obtained 80 percent of their moisture from the upper 2 ft and a little more than 90 percent from the upper 3 ft." Thornthwaite and Mather (14), quoting several sources, give data for cotton, alfalfa, and mature orange trees. Table 1 is adapted from their data.

TABLE 1. PERCENTAGE OF WATER OBTAINED BY PLANTS FROM THE UPPER 2 AND 3 FT

Crop	Soil	Percent of water from 2 feet	3 feet	Third foot
Cotton	Heavy clay	82	88	6
Cotton	Sandy loam	62	82	20
Cotton	Clay loam	59	76	17
Alfalfa	Fine sandy loam	62	77	15
Mature orange trees	Sandy loam	67	82	15

The relative amounts of moisture derived from each successive foot of soil, coupled with recent information on the movement of water in soils (a complete discussion of which is reserved for a later paper), suggest that practically all the water used by plants is derived from the zone of greatest root ramification plus a tributary zone which is about 35 cm or 14 in. It is somewhat greater for fine-textured soils and somewhat less for coarse-textured soils. The work of Rode (6), Bol'shakov (15), and Abramova (16) suggests that the proportion of water in the tributary zone that can move freely into the root zone proper is approximately 30 percent

of field capacity for heavy soils and 50 percent for light soils. Several checks made at Seabrook, N. J., under the author's direction confirmed the concept of the "effective root zone".

With these concepts cleared up, we now find ourselves in pretty much the same position as the river hydrologist who tries to estimate expectancies of floods. He is not always fortunate to have enough past records of river stages. Quite often he must derive his floods from past records of rainfall and other elements for which records are more generally available. Our problem is analogous, except that we never have a sufficient record of soil moisture and must always derive our values of moisture deficiency from other more readily available data.

To determine what data we may use, we must first set up a functional relationship between soil moisture and the factors which determine it. In the simplest possible terms this relationship can be expressed in the following manner:

$$M_{t_2}=M_{t_1}+(P-E) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [1]$$

In this expression M_{t_1} and M_{t_2} are the moisture contents of the soil at consecutive times t_1 and t_2. P is the "effective precipitation" during the period t_2-t_1 and E is the evapotranspiration during the same period.

The term "effective precipitation" will be explained before proceeding much further. Soil moisture is divided into several categories. Rode (6) lists six major ones. The sixth, which he calls "free water", is subdivided into five subcategories. In many practical problems including irrigation we are primarily concerned with the two subcategories known as field capacity (FC) and wilting coefficient (WC), the latter being the level below which soil moisture becomes practically constant under natural conditions. In soils suitable for irrigation, the commonly known well-drained soils, moisture in excess of field capacity is transitory, remaining in the soil for only short periods of time. Therefore, any amounts of precipitation greater than the difference between field capacity and the actual moisture content of the soil need not be considered.

SUMMER PRECIPITATION RATES

In regions like the eastern United States an appreciable part of the summer precipitation occurs at rates that exceed the infiltration capacity of the soil even when its moisture content is below field capacity. On level or nearly level ridge land such intense rainfall results in only temporary ponding on the soil surface. On sloping portions of a field this part of the rainfall runs off and the effective precipitation is less than the recorded by an amount equal to the runoff. On level portions of a field receiving runoff from adjoining sloping parts, the effective precipitation is greater than the recorded by the amount of runoff from the tributary area. Krimgold and Beenhouwer (17) recently analyzed the infiltration data obtained by Free, Browning, and Musgrave in 1937 (18) and similar data reported by Mamanina (19) in 1951. This analysis resulted in a set of quantitative expressions from which required values of infiltration rates can be determined for a wide range of soils in the humid regions of the United States. The investigation carried out by the author in connection with the Air Force contract (2, 20) resulted in expressions from which amounts of rainfall occurring at rates greater than any given infiltration capacity can be estimated from total rainfall and air temperature.

From what we said it follows that, if we begin with a date at which the soil is at field capacity, we can rewrite our expression in the following manner:

$$M_t=(FC)-(E_t-P_t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [2]$$

In this expression M_t is the moisture content in the effective root zone at the end of any period; FC is the moisture content at field capacity; E_t and P_t are evapotranspiration and effective precipitation and E_t-P_t is the moisture depletion for the period t. A moisture deficiency exists after M_t becomes less than $K\ (FC)$, the lower limit of the optimum range—the coefficient K being 0.5 and 0.7 for coarse-textured and fine-textured soils, respectively. For moisture contents between $M_t \leq K\,(FC)$ and $M_t \geq WC$, the moisture deficiency (MD_t) is equal to E_t-P_t. MD cannot be greater than $K\ (FC)=WC$, because, after the wilting coefficient is reached, soil moisture is affected but little by either transpiration or evaporation.

DAILY MOISTURE DEFICIENCIES

With the large amount of information now available we can determine or estimate FC and WC. We can select the proper value for K and, where necessary, determine the effective precipitation P. But we still cannot determine daily moisture deficiencies unless we have a method for deriving values of evapotranspiration from other readily available data. To be suitable for our purpose such a method must meet the following requirements:

1 It must be capable of giving daily values.

2 It must involve factors which do not vary too widely in space and for which reliable data are available at a maximum number of locations.

3 It must give values of evapotranspiration of an accuracy comparable to that attainable in the determination of the other factors involved—field capacity, wilting coefficient, and effective precipitation.

4 The computations involved must not be overly complicated or time-consuming, or must be capable of being reduced to time-saving nomograms and tables.

Blaney and Criddle (21), Penman (22), and Thornthwaite (23) have devised formulas and methods for estimating evapotranspiration from existing data. Of these Thornthwaite's method appears to meet the four requirements best. An added advantage of this method is that the greatest part of the work involved has already been done for all U.S. Weather Bureau stations in the United States and numerous stations in other parts of the world so that evapotranspiration can be computed readily for a large number of locations. The author's experience with the formula indicates that it requires some refinement and revision. This view is shared by the formula's originator under whose direction a great deal of work is now being done to eliminate the shortcomings. However, the numerous tests to which the formula has been subjected suggest that, even in its present form, it gives acceptable values for summer months.

Thornthwaite (23) developed his formula and his method primarily to determine what he calls "the moisture factor in climate," which he used as a basis for his climatic classification of 1948. For this purpose he quite legitimately resorted to a number of generalizations. One of them is that ". . . regardless of its texture the soil reservoir contains only 10 cm of water on which plants can draw" (24). This state-

ment has been hotly disputed by agronomists and soil scientists, some of whom used it as an excuse for rejecting Thornthwaite's method, thus depriving themselves of a very useful tool. This of course is absurd, because the assumption of 10 cm (4 in) has nothing to do with the validity of the formula for computing evapotranspiration and because, as is amply demonstrated in this paper, it does not necessarily enter into the computation of moisture deficiencies.

One could legitimately question another implied assumption, namely, that evapotranspiration takes place at the same, maximum (potential) rate over the entire range of soil moisture, from the wilting coefficient to field capacity. But even this objection is not too serious when the formula is used as in this paper.

There is still another frequently voiced objection to both Penman's and Thornthwaite's assumption namely, that under the same climatic conditions all plants transpire essentially the same amounts of water when the moisture supply is unrestricted. The author scrutinized closely the "monthly measured evapotranspiration at Seabrook, N. J.," reported by Thornthwaite and Mather (14) and the more detailed information on crop conditions and computed evapotranspiration (25). A comparison of the August records from the evapotranspirometers, which were in corn in 1948, with the records for 1949, when they were in lima beans, shows no difference in the monthly use of water between these two crops that could not be well accounted for by differences in meteorological conditions. However, the records for 1950, when all the evapotranspirometers were in grass, show a somewhat higher evapotranspiration in August even though the meteorological conditions, as indicated by computed evapotranspiration, would call for somewhat lower values. Measurements of soil moisture made under the direction of the author in July, 1953, on adjacent irrigated fields of snap beans and sweet corn in comparable stages of growth indicate a higher use of water by corn than by snap beans. Alpatiev (5) studied this problem in the vicinity of Leningrad where soil moisture conditions during the growing season are normally within the "optimum range" as defined in this paper. His results indicate no differences between evapotranspiration by the following crops—barley, peas, buckwheat, flax, potatoes, sunflowers, and cabbage—that cannot be ascribed to differences in meteorological conditions (temperatures, winds, etc.).

USE OF WATER BY VARIOUS PLANTS

The evidence is thus still inconclusive; it does, however, by and large appear to support the view that under potential conditions, which are fairly well approximated with good irrigation practices, the difference in use of water by various plants at comparable stages of growth may not be as great as some people believe. The satisfactory agreement between measured soil moisture during summer months and values computed by Thornthwaite's method suggest that the error due to neglecting the difference in water use by various crops is much smaller than that introduced by trying to eliminate it with "crop-consumptive use coefficients". The "computed" and "corrected" deficiencies in Table 2 of Allred and Chen (26) suggest that these "coefficients" when applied in "humid" regions result in values that are not of the proper order of magnitude.

TABLE 2. MARCH-NOVEMBER PRECIPITATION AT BRIDGETON, N. J., 1931-1952, IN RELATION TO THAT FOR 1883-1952 (67 YEARS)

(No record for 1925, 1928, 1929)

Order of magnitude	Year	March-November precipitation, in	Order of magnitude	Year	March-November precipitation, in
5	1934	42.04	33	1950	33.37
6	1948	42.01	35	1937	33.01
9	1938	39.68	36	1946	33.00
11	1940	39.48	37	1942	32.68
13	1935	39.25	41	1951	31.86
15	1944	38.21	44	1931	30.62
21	1933	36.64	46	1939	30.35
22	1945	36.51	51	1949	28.97
25	1936	35.81	54	1947	28.47
26	1952	35.60	57	1941	27.07
28	1932	34.79	58	1943	26.66

With the problem stated in terms of functional relationships and with means available for expressing these relationships in terms of readily available data, our task resolves into (a) computing moisture deficiencies for each of a number of representative years, (b) expressing them in a manner suitable for probability analysis and (c) determining the expectancies for deficiencies of varying degree.

The relationships elucidated in this paper were utilized in determining the feasibility of supplemental irrigation on the light-textured soils of Seabrook Farms. The crops grown on these soils include peas, sweet corn, beets, broccoli, snap beans, lima beans, spinach, and other vegetables, as well as cover crops such as rye, clover, and ryegrass, all with root zones of approximately 0-18 in. The tributary zone for these light soils was estimated to be 10 in. The effective root zone, therefore, varies from 10 in at planting time and for a short period thereafter to 28 in when the crops are well established. With successive plantings and two crops per year, the growing season is from March to November. Field capacity of the several soils included under the "light soils" at Seabrook varies from 0.13 in per in for Sassafras loamy coarse sand to 0.17 in per in for Sassafras coarse sandy loam. The mean value of 0.15 in per in was used for the entire group. The wilting coefficient is 0.04 in per in. There are no important changes in the texture of these soils within the first 3 ft. Field capacity of the effective root zone, therefore, ranges from 1.5 in (10 x 0.15) during the early stages of growth to 4.2 in (28 x 0.15) during the period of normal depth of root penetration which for most crops begins two or three weeks after emergence. In accordance with our scheme the limiting values of moisture for the root zones are as follows:

Effective root zone, in	*FC*, in/in	*FC*, in	*WC*, in/in	*WC*, in	*K*	$LOR = K(FC)$, in	$MD = LOR - WC$, in
10	0.15	1.5	0.04	0.4	0.5	0.75	0.35
28	0.15	4.2	0.04	1.12	0.5	2.1	0.98

NOTE: In the above table FC = field capacity, WC = wilting coefficient, LOR = lower limit of the optimum range of moisture, MD = maximum moisture deficiency, and the coefficient $K = 0.5$.

The temporary, shallow effective root zone must be considered in estimating economic feasibility, because deficiencies during germination and early stages of growth always affect ultimate yields adversely. For this reason moisture deficiencies were computed and analyzed for both root zones. In the computations for the 10-in root zone Thornthwaite's formula must be corrected during periods when the surface of the soil is dry. Space will not permit discussion of this in

TABLE 3. MOISTURE CONTENT IN LIGHT SOILS, SEABROOK, N. J.

Effective root zone = 28 in, May, 1939

$FC = 0.15$ in/in $\quad FC = 4.20$ in
$WC = 0.04$ in/in $\quad WC = 1.12$ in
$K = 0.5 \quad MD = 0.98$ in $\quad LOR = 2.10$ in

Date	Evapotranspiration, E, in	Precipitation, P, in	Moisture depletion and accretion, E-P, in	Moisture content, in	Moisture deficiency daily, in	Moisture deficiency accumulated, in
1	.05	T	−.05	4.05		
2	.06		−.06	3.99		
3	.06	T	−.06	3.93		
4	.09		−.09	3.84		
5	.10		−.10	3.74		
6	.14		−.14	3.60		
7	.17		−.17	3.43		
8	.16		−.16	3.27		
9	.16		−.16	3.11		
10	.15		−.15	2.96		
11	.15		−.15	2.81		
12	.09		−.09	2.72		
13	.05	.22	+.17	2.89		
14	.06	.09	+.03	2.92		
15	.06		−.06	2.86		
16	.06		−.06	2.80		
17	.07		−.07	2.73		
18	.12		−.12	2.61		
19	.14		−.14	2.47		
20	.18		−.18	2.29		
21	.20		−.20	2.09	.01	.01
22	.19	.03	−.16	1.93	.17	.18
23	.17	.23	+.06	1.99	.11	.29
24	.15		−.15	1.84	.26	.55
25	.10		−.10	1.74	.36	.91
26	.15		−.15	1.59	.51	1.42
27	.17		−.17	1.42	.68	2.10
28	.23		−.23	1.19	.91	3.01
29	.21		−.21	1.12	.98	3.99
30	.19		−.19	1.12	.98	4.97
31	.22		−.22	1.12	.98	5.95

detail. The procedure followed for the shallow root zone, except for the correction referred to above, is identical with the one outlined for the 28-in zone.

In determining feasibility, it is important to select a representative period so that the moisture deficiencies derived from the data will represent a good sample of past experience. Since temperatures do not vary nearly as much as precipitation, it was the latter that was considered in selecting the period. An examination of the 67-year record at Bridgeton, N. J., indicated that the 22-year period 1931-1952 might prove adequate. The March-November precipitation for each year and the order of magnitude of each value in the longer 67-year period are shown in Table 2. The daily evapotranspiration for the provisionally selected period was computed with Thornthwaite's formula. What he aptly called a "simple bookkeeping procedure" was used to obtain daily values of moisture depletion. Beginning on March 1, when the soil was at field capacity, an ordinary ledger was kept in which effective precipitation was added and evapotranspiration subtracted. The algebraic sum of the two was the accretion or depletion of soil moisture. For the nearly level soils at Seabrook the recorded precipitation was assumed to be equal to the effective precipitation.

The first five columns in Table 3 illustrate the bookkeeping procedure essentially as used by Thornthwaite. The accumulated daily deficiency divided by the number of days with moisture deficiency represents a numerical index of the degree of deficiency. Thus the accumulated deficiency of 5.95 in in Table 3 divided by 11 days gives an average daily deficiency of 0.54 in in the 28-in root zone, a little over half the maximum possible moisture deficiency of 0.98 in. This value indicates that, without irrigation, crops in 1939 did well until May 21st but suffered a serious setback during the last ten days of May. Computations similar to those shown in Table 3 were made for each day of the 22 years and average moisture deficiencies were computed for each of 22 growing seasons (March-November). These values, arranged in order of magnitude together with other pertinent information are shown in Table 4. In Fig. 1 are shown the expectancies of various moisture deficiencies. The distribution of the plotted points confirms the adequacy of the selected period of record. From Table 4 and Fig. 1 we find that deficiencies occurred in each of the 22 years. The number of days with moisture deficiencies ranged from 42 in 1934 to 135 in 1949. An average deficiency of 0.46 in can be equalled or exceeded 99.9 percent of the years, i.e., practically every year. Fifty percent of the years, i.e., every other year, one could expect the deficiency to be equal to or greater than 0.74 in, which would result in a serious reduction in crop yields. These conclusions from our analysis are amply supported by actual practice in the part of southern New Jersey where irrigation is a common practice and where all large commercial truck crop farms, including Seabrook Farms, have used supplemental irrigation and found it profitable in "wet" and "dry" and in "good" and "bad" years.

The most important implication of this paper is that with satisfactory methods of deriving values of evapotranspiration, soil moisture, and effective precipitation from readily available data, it is now possible to solve many problems in agricultural climatology and agricultural hydrology that have defied adequate solution. With proper allowance for soils, crops, and the practical aspects of water application, we can now schedule irrigation without costly time-consuming field

TABLE 4. MOISTURE DEFICIENCIES IN LIGHT SOILS AT SEABROOK, N. J., 1931-1952

Year	Accum. deficiency, in	Days with deficiency, no.	Average daily deficiency, in	Consecutive days with moisture deficiency May	Jun	Jul	Aug	Sep	Oct	Nov
1943	94.4	102	.93		10	31	31	30		
1947	106.4	121	.88			27	31	30	31	2
1940	51.8	60	.86		13	31	16			
1935	54.3	66	.82			31	31	4		
1949	110.0	135	.81		18	31	31	29	26	
1941	90.7	113	.80	13	3+3	6+4+6	18+3	30	27	
1952	91.6	115	.80		14	9+13	6+3	25	31	14
1939	76.7	98	.78	11	30	31	18	8		
1942	80.6	105	.77	28	30	1+25	9	12		
1944	69.6	91	.76	15	18	27	1+18	12		
1937	56.8	75	.76			29	22	3+12	9	
1932	81.1	109	.74		24	27	23	30	5	
1951	56.0	76	.74			4+20	31	1+12	8	
1931	84.0	116	.72		11	31	10	20	28	16
1950	47.5	67	.71			7+19	31	10		
1948	56.2	81	.69			20	5	30	23+2	1
1936	39.2	58	.68	21	11	3	16	7		
1934	28.0	42	.67		4+3+10	12	6	7		
1945	35.3	54	.65		16	14		17	7	
1938	37.8	60	.63	6	13	7	16	18		
1933	55.4	93	.60		26	7	17		31	12
1946	53.3	95	.56		13	22	6	3+3	12+15	21

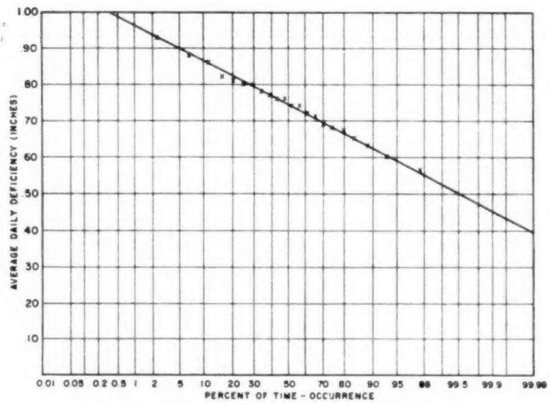

Fig. 1 Expectancies of average moisture deficiencies

determinations and with confidence that the results will be at least as good as those obtained with various devices such as tensiometers, resistance blocks, etc.

The great majority of practical problems involve risks which can be evaluated rationally only by estimating probabilities of occurrence or expectancies. With records of temperature and amounts of rainfall we now can estimate with acceptable accuracy such important factors as the expectancy of amounts of surface runoff, stream flow, evaporation from water surfaces, dependability of water supply, optimum times of seedbed preparation and planting, probable dates of maturity and harvest, and can obtain a great many other vital items of information that are required for proper planning and successful execution of a modern agricultural enterprise—one of the most, if not the most, complex undertaking of our civilization.

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Farm Dairy Buildings

(Continued from page 21)

5 *Decrease the investment cost of dairy buildings.* This also offers an opportunity for important research and engineering design. Most of the annual cost is fixed by overhead in the form of interest and depreciation or by cash expense for taxes and insurance. The objective should be an investment such that the annual building cost would not exceed about 10 percent of gross income. Under the conditions of this study the investment should not be more than the estimated replacement cost of $375 per animal unit for present structures.

In the research study it was found that building inventories varied only slightly with differences in herd size. The age of the barns, their replacement cost or the structural quality of the buildings appeared to have little relation to functional utility. Space was wasted in haylofts and on farms where small herds were housed in remodeled barns. Crowded conditions showed lack of flexibility. Decisions based on suitable plans, engineered design, and research findings should result in more flexible buildings, greater economy, and better functional characteristics.

The analysis of functional utility indicated that the greatest needs for improvement were in dairy stalls, mangers, alleys, gutters, water protection, external layout, cleaning operations, and facilities for cleaning cows. These are problems that can be solved by planning without much increase in the investment cost.

The planning suggestions offered to overcome deficiencies observed in the study were centered on such improvements as (1) loose-housing designs, with elevated stalls, (2) arrangements to permit expansion of a herd with minimum addition of structures, (3) flexibility in the use of buildings, (4) ground-level hay storage, (5) remodeling to obtain better travel routes or better use of space, (6) one-story stall barns or open-shelter buildings, and (7) organization of yards and buildings for labor efficiency. These should be continuing problems in farm structures.

Culverts as Water Runoff Measuring Devices

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A WAY to use highway culverts to measure runoff rates is described in this paper. The motive for this study was the need for runoff data from small watersheds in all sections of the country. Since the rectangular highway culvert is also distributed nation-wide, its use for this purpose was practically self-suggestive. Furthermore, studies of the hydraulics of the highway culvert showed that, under certain conditions, it could be a good flow meter. This combination of circumstances indicated that here would be a rewarding field for research. Accordingly a cooperative study along this line was undertaken jointly by the Soil Conservation Service of the U. S. Department of Agriculture and the Oklahoma Agricultural Experiment Station. As a result of this study, a simple, relatively inexpensive flow gaging station has been developed using the highway culvert as the primary measuring device. The method has been field tested by employing it on three small watersheds near Stillwater, Okla.

Present knowledge of the hydraulic behavior of culverts makes their use in hydrologic investigations practicable. Mavis(1)* has shown that the discharge through culverts flowing part full and with free outfall is dependent only on the upstream water-surface elevation. The relationship between depth of water above culvert entrance and the discharge rate is well defined and stable, provided that flow depth downstream from the culvert entrance is less than critical depth. Thus a single measurement of the depth of water upstream from the culvert entrance will determine the discharge rate. After a culvert entrance has been calibrated a depth-recording gage placed immediately upstream will obtain the necessary runoff data. Fig 1 shows a rectangular concrete culvert being used as a gaging station.

Culverts which have a free outfall are preferred for flow-rate measurement. However, some of those that flow part full and partially submerged can also be used, provided that submergence at the outlet does not result in flow depth greater than critical depth immediately downstream of the culvert entrance.

A modification of the standard culvert is needed if very small rates of flow are to be measured accurately. A practical answer to this problem is the weir sill developed by Villemonte(2). A modification of this sill in place in a 4 x 8 ft concrete culvert is shown in Fig. 2. The Villemonte weir sill consists of two triangular, tapered, converging sills placed on the culvert floor at a 30-deg angle to the direction of flow, with a narrow opening left between them. This narrow opening, or throat, controls the depth of small flows which pass through it, causing the flows to be of measureable depth. As the flow rate increases, the weir sills are submerged and the control gradually passes to the culvert entrance. Thus a culvert, which flows part full with free outfall and which is provided with a weir sill, is a good flow meter. Discharge rates from the very low to the maximum capacity of the culvert can be measured with satisfactory accuracy.

The Villemonte weir sill was chosen for this study for several reasons. First, the form of the weir sill was accepted on the basis of the previous studies. Second, the weir sill does not reduce the maximum capacity of the culvert in which it is placed. Finally, because of its shape, the sill will not become fouled easily with debris, nor will the throat become clogged with sediment.

The sill used in these experiments is very similar to the Villemonte weir sill. It differs in being about one and one-half times as large in height and in throat opening as the Villemonte sill for a culvert of the same width. Fig. 3 shows a sketch of the weir sill, which has been standardized with all dimensions being proportional to the culvert width, *W*.

Models of culverts equipped with weir sills were constructed and tested. The objectives of these experiments were to determine: (a) a location for the weir sills near the culvert entrance that would not adversely affect the hydraulic performance of the sills or the culvert, (b) the head-discharge relationship of culverts equipped with weir sills, (c) the effect of culvert slope on the head-discharge relationship, (d) the effect of the culvert shape on the head-discharge relationship, and (e) the minimum measurable discharge rate for weir sills on various culvert slopes.

This paper was presented at the annual meeting of the American Society of Agricultural Engineers at Pittsburgh, Pa., June, 1953, as a contribution of the Soil and Water Division.

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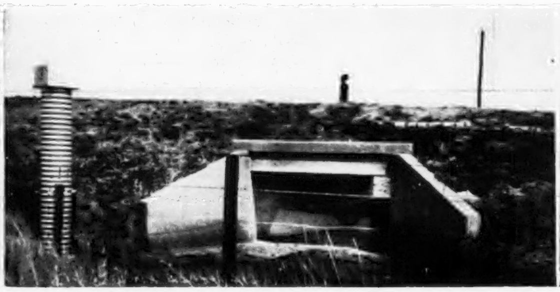
*Numbers in parentheses refer to the appended references.



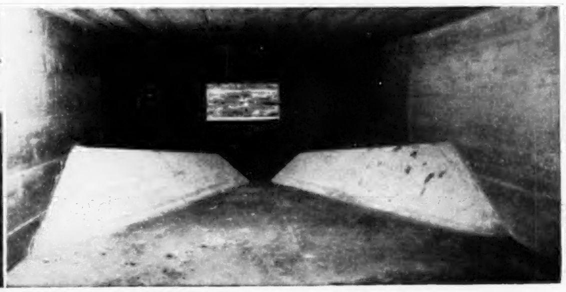


Fig. 1 *(Left)* The entrance of a 4-ft deep, 8-ft wide rectangular highway culvert equipped with weir sills, depth-recording gage, and gage well • Fig. 2 *(Right)* Precast weir sills installed in a 4-ft deep by 8-ft wide highway culvert

Two model setups were used in these studies, one indoors and the other outdoors. Low-flow tests were made on the indoor model while the moderate and high-flow tests were conducted on the outdoor model.

The outdoor setup is shown in Fig. 4. The model in place for testing is an 8-in full model. This particular model was the first one tested and served as a pilot model for subsequent experiments.

Fig. 5 shows one-half of a 16-in wide culvert in position for testing in the indoor setup. By using the half model the water-surface profile could be viewed through the glass panel placed along the center line of the culvert. Similar half models were used in the outdoor setup for all tests except those on the pilot model.

Essentially each model setup consisted of a source of water with a constant head, a rate-measuring flume, an entrance forebay equipped with suitable baffles, a depth recorder to indicate when steady flow existed, the culvert model, and a profiling apparatus with a point gage measuring to the nearest 0.01-in mounted over the model. This profiler permitted measurement of the slopes and depths of water at any point in the model. The top was left off the model so that these measurements could be made. Where full flow was anticipated the top was fixed in place.

The floors of all models, except the pilot model, were hinged at the entrance to permit testing on various slopes up to 6 percent. All models were constructed of white pine, sanded smooth, and coated with two coats of spar varnish. Dimension changes during testing were negligible. Culvert entrances were square edged at the top and had 30-deg angle wing walls at the sides with sharp corners at the junction.

Sixty-two different arrangements of the culvert models were tested. These covered culvert floor slopes from zero to 6 percent, and ratios of culvert depth to width from 0.375 to 1.5. Each of these arrangements was subjected to about 25 test flows ranging from a practical minimum to the maximum capacity of the model.

RESULTS OF MODEL EXPERIMENTS

The first model tested was one without weir sills. These tests were made to provide the necessary comparison for culverts with weir sills. Also studies were made of the water-surface profiles these first tests to determine a probable good location for the weir sills.

Fig. 6-A shows the head-discharge relationship of a typical concrete culvert 8 ft wide, 4 ft deep, and without weir sills. Note that in this figure the head is referred to culvert floor at the culvert entrance. With a floor slope of 2 percent and a free outfall the culvert barrel flowed part full even when the entrance was submerged. The entrance alone thus controlled the head-discharge relationship. It is evident that two laws governed the flow. Critical depth of the entrance cross section controlled the flow until the culvert entrance was submerged. The actual discharge in this range agreed within one percent with the theoretical discharge if flow depth at entrance is assumed to be at critical. Flows submerging the entrance occurred as sluice gate or orifice flow.

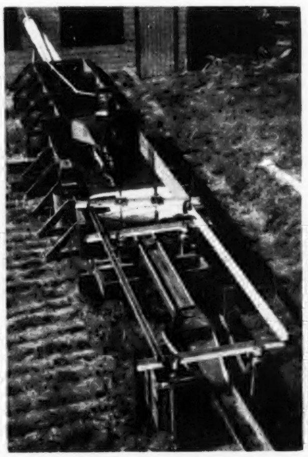
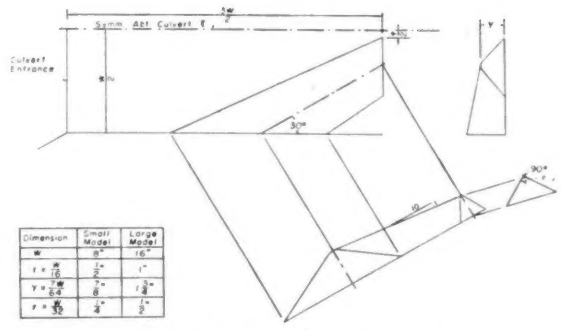


Fig. 4 The outdoor model setup. The model in place is a full culvert 4 in deep and 8 in wide



Dimension	Small Model	Large Model
W	8"	16"
$t = \frac{W}{16}$	$\frac{1}{2}$"	1"
$Y = \frac{7W}{64}$	$\frac{7}{8}$"	$1\frac{3}{4}$"
$r = \frac{W}{32}$	$\frac{1}{4}$"	$\frac{1}{2}$"

Fig. 3 Dimensions of model weir sills

Observations of the water surface profiles in the culvert suggested that the weir sills be located with the throat a distance $1\frac{1}{2}$ W downstream from the culvert entrance. All subsequent tests were made with the weir sills at this location. The sills were far enough downstream to prevent choking the culvert entrance yet near enough to the entrance to enable head measurements to be made upstream. Fig. 6-B illustrates the effect of the weir sills on the changing of the flow control as the discharge rate increases. The head for this plotting is referred to the culvert floor at the weir sill throat. Low flows are controlled by the weir sill throat with control shifting gradually to the culvert entrance for higher flows. Throughout these shifts of control the flow condition is stable and only one discharge rate is possible for a given head. The culvert barrel flowed part full throughout this range.

The advantage of the weir sill is the more accurate measurement of the low flows. However, a disadvantage is also evident from Fig. 6-B. The rating curve is very flat for part of the intermediate flow rates. In this range a culvert with weir sills is a less sensitive measuring device than one without.

To provide a direct comparison of the curves on Figs. 6-A and 6-B these curves are plotted again on Fig. 7 to a common datum, with head being referred to culvert throat at entrance. Evident immediately is the coincidence of the two curves when the submerged flow condition is reached. Thus the presence of the weir sills does not reduce the maximum capacity of the culvert.

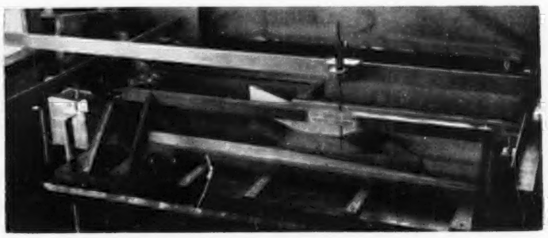
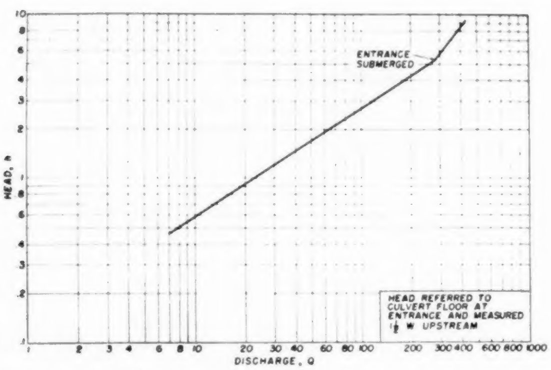


Fig. 5 Indoor model setup. The test flow is confined to the weir sill throat. The point gage for depth measurement is upstream of the weir sill throat and downstream of the culvert entrance



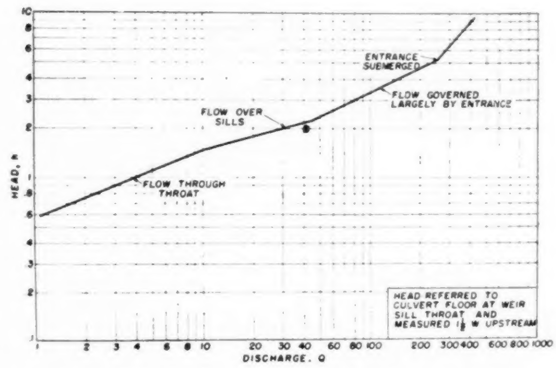


Fig. 6A *(Left)* Generalized head-discharge relationship of culvert without weir sills • Fig. 6B *(Right)* Generalized head-discharge relationship of culvert with weir sills

A plotting of the data from the experiments on culverts on a 2 percent floor slope is shown on Fig. 8. (The plottings for the experiments on the other slopes are omitted for brevity's sake. A technical bulletin giving all results is in process of publication.) The points are actual observations. The dashed lines are the plots of the equations which are the best fit of the data. Where a simple functional relationship existed between head and discharge rate the equation was derived by analytical means and the coefficients and exponents evaluated by statistical methods. In the transition zones no attempt was made to write the equation for the head-discharge relationship. Instead the observed points are connected with a solid line which represents the best visual fit.

The data are presented in dimensionless form. Culvert width is the base dimension. Thus head is expressed at the ratio of head to culvert width, or h/W. Discharge is the ratio of discharge rate to culvert width to the five-halves power, or $Q/W^{5/2}$. The culvert cross-section is described by the ratio D/W, where D is the depth of the culvert. Expressed in this form the data are of greatest usefulness and can be readily adapted to any width culvert.

The head on a culvert equipped with weir sills is defined as the difference in elevation between the floor of the culvert at the weir sill throat and the level water surface a distance 1½ W upstream from the culvert. This method of head determination is satisfactory for the flows controlled by the weir sill. When the control shifts to the culvert entrance, the proper reference point would be the culvert floor at entrance. Or if the orifice-flow law governed, the proper head reference point would be the elevation of the center of the culvert opening. Since changing the point of zero head for each type of flow would be confusing, all heads are referred to the culvert floor at the weir sill throat.

The Rating Curve of the Culvert with Weir Sills. As previously mentioned the flow control shifts from the weir sill throat for low flows to the culvert entrance for higher flows. Flows resulting from heads less than $h/W = 0.113$ are contained within the weir sill throat. This part of the head-discharge curve plots as a straight line on logarithmic paper and can be expressed by the equation

$$Q/W = 2.404\,(h/W)^{2.195}$$

This equation applies to all slopes tested.

Flow for heads of $h/W = 0.113$ to $h/W = 0.18$ is through a combination of the trapezoidal section and the flat V-notch section of the weir. This combination of controls results in a skewed head-discharge curve for which no equation has been derived. A photograph of this flow condition is shown in Fig. 9.

When flow depths exceed $h/W = 0.18$, the entrance begins to exercise some control over the flow, although the sills remain the primary control. As the stage increases the primary control gradually shifts to the culvert entrance. When this occurs, critical depth flow governs, provided that the culvert slope is equal to or greater than the critical slope and that the culvert has a free outfall.

When flow depths become great enough to submerge the culvert entrance, a marked change occurs in the head-discharge relationship, as indicated by the steeper lines on Fig. 8. The data for these tests were analyzed by assuming that the orifice flow law governed the head-discharge relationship. By plotting the values of $Q/W^{5/2}$ against the corresponding values of h_o/W, where h_o is the head with respect to the center of the opening and where S is the slope of the culvert floor expressed in percent, there results the following equation:

$$Q/W^{5/2} = 4.416\,(D/W)^{-0.0912}\,S^{0.0158}\,D/W\,(h_o/W)^{0.588}$$

The dashed lines in the orifice flow range on Fig. 8 are graphical representations of this equation, and in general the fit of this equation to the data is good. Note that the culvert barrel still flowed part full. Also for submerged entrance flow a culvert floor slope greater than critical is not a necessary requirement for entrance control. This equation also applies to all slopes tested.

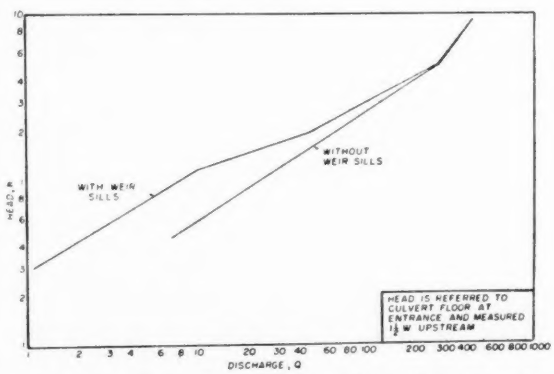


Fig. 7 Comparison of the rating curves for a culvert with and without weir sills

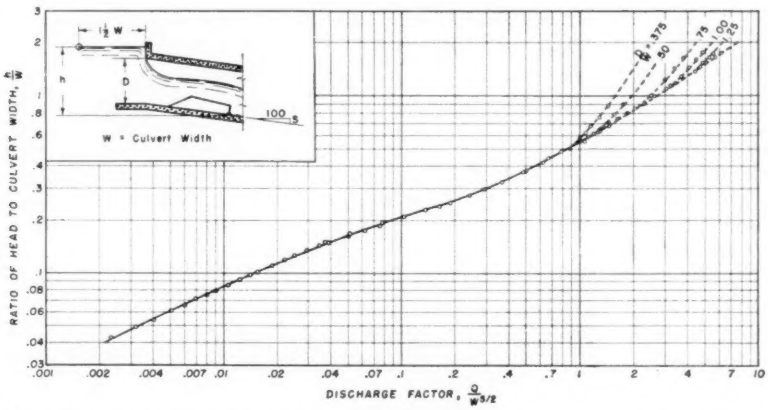


Fig. 8 Dimensionless rating curve for culvert with weir sills. Culvert floor slope is 2 percent

Effect of Culvert Slope on Minimum Measurable Discharge Rate. Since the datum for head measurement, the weir sill throat, is lower than the culvert entrance, there is some minimum head at the gaging station representing the beginning of control by the weir sills. The sill does not control the upstream-flow depth until the backwater curve from the weir sill submerges the culvert entrance and extends to the gage well. This minimum measurable head will depend on the culvert slope, since the steeper the culvert the lower the weir sill throat will be below the entrance. The values of the minimum measurable discharge rates corresponding to these heads for the various slopes were determined from the rating curves similar to Fig. 8. The point at which the rating curve breaks away and becomes nearly horizontal in the very low flow range is the point where flow control by the weir sill throat ceases. Fig. 10 shows the logarithmic plot of the values of $Q/W^{5/2}$ and their corresponding culvert slope.

Construction and Installation of Weir Sills. Prefabricated weir sills constructed of light-weight aggregate concrete were installed in concrete culverts as measuring devices for three experimental watersheds in March, 1952. The culverts selected included a 4-ft high by 8-ft wide twin barrel, a 4-ft high by 8-ft wide single barrel, and a 3-ft high by 3-ft wide single-barrel culvert. The sills for the 8-ft wide culverts were each cast in two sections while each sill of the 3-ft culvert was cast in one piece. The sills were attached to the culvert sides and floor with mortar. No other anchorage was used.

The prefabrication of weir sills may be easily accomplished by making use of a right-angle trough form, the bottom corner of which is used as the reference line for all layout dimensions. Fig. 11 shows the trough form and the layout dimensions for prefabricating the weir sills. Removable bulkheads are set in position to form the ends of the sill. The rounded crest of the weir sill can be formed by fastening a piece of sheet metal, curved to the proper radius, to the sides of the trough form. For the smaller sills a length of pipe of proper outside radius may be anchored to the concrete sill to form the weir sill crest. *(Continued on page 39)*

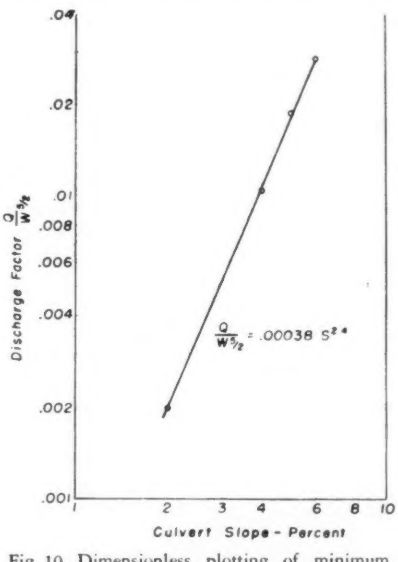


Fig. 10 Dimensionless plotting of minimum measurable discharge rates for culverts equipped with weir sills for various floor slopes

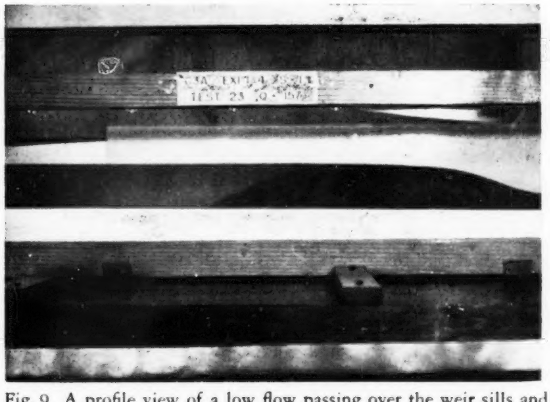


Fig. 9 A profile view of a low flow passing over the weir sills and controlled by them

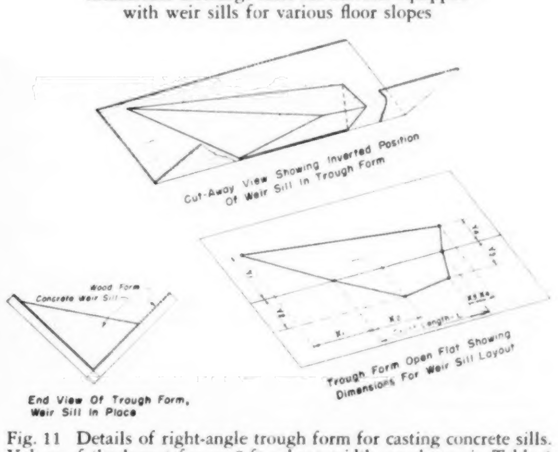


Fig. 11 Details of right-angle trough form for casting concrete sills. Values of the layout for an 8-ft culvert width are shown in Table 1

Flexible Pipe for Irrigation Water Under Low Pressure

Vaughn E. Hansen
MEMBER ASAE

A FABRIC pipe for use in irrigation was recently placed on the market under the trade name "Fibrylon Irrigator." It has a light-weight fabric base of spun glass with vinyl coating both inside and outside, is manufactured in sizes from 3¼ to 16 in in diameter, and may be obtained with or without attached spiles for row distribution. It was introduced as a means of conveying and distributing irrigation water under low pressure for surface irrigation when other methods are not satisfactory.

The manufacturer claims a number of advantages for this product, namely: it saves water through elimination of conveyance losses, it saves time and fuel since long ditches need not be filled, the system serves rolling land where ditches may be impractical, little head land is wasted as is usual with ditches, the maintenance problem associated with irrigation ditches is eliminated, and the system is easily portable. The product is advertised as fire-resistant, waterproof, rot-resistant, strong; will not shrink, stretch, or deteriorate with exposure to sun and weather, and requires little special care for storage. The pipe carries a one-year guarantee against defects in material and workmanship.

This flexible pipe has been on the market such a short time that its use is still largely experimental and its limitation and real value is as yet not completely determined. It seems quite possible, however, that this pipe may prove to be a valuable contribution to irrigation if the characteristics and hence the usefulness of the pipe can be determined, even though its economical use may be restricted to specialized distribution problems.

Both the Operations and Research Divisions of the Soil Conservation Service expressed considerable interest in the practical application of this new irrigation aid; however, through correspondence with the company, it was found that little was known regarding the hydraulic characteristics of the flexible pipe. The manufacturer indicated that, because of the lack of laboratory facilities, they had no substantial and reliable data on the hydraulic characteristics. To assist in a study of these qualities, the company furnished sections of its flexible pipe on which the investigation reported herein was made.

Report of a project developed under the Research and Marketing Act, Project W-9, the eleven western states, Hawaii, and Alaska cooperating. The project was conducted under a Memorandum of Understanding between Utah Agricultural Experiment Station and the Division of Irrigation and Water Conservation, Soil Conservation Service, USDA, with the cooperation of the Holton Corporation, manufacturers of Fibrylon Irrigator flexible pipe. (NOTE: The Mobile Plastics Division, Carlisle Corporation, has since purchased the Holton Corporation.)

The author — VAUGHN E. HANSEN — is irrigation engineer (BPISAE), U.S. Department of Agriculture, and research associate professor, Utah Agricultural Experiment Station.

Acknowledgments: The author expresses appreciation to the Holton Corporation for the Fibrylon Irrigator furnished for the investigations reported in this paper; to C. W. Lauritzen of the Soil Conservation Service, who conducted the accelerated deterioration tests; to Gordon Flammer who conducted the majority of the field tests, and to Preston Olsen who prepared the head-discharge curves for the hinge type of control.

INVESTIGATIONS

The following studies were made on Fibrylon Irrigator flexible tubing furnished by the manufacturer: (1) accelerated deterioration tests, (2) bursting pressure determinations, and (3) control and measurement of the flow from spiles.

Accelerated Deterioration Tests

Accelerated deterioration tests have been in progress on this material during the past four years. These tests consist of burying the material in a soil compost maintained in the moist condition at 80 F. The compost consisted of a fertile soil with manure and ammonium nitrate added. The activity can be judged by the fact that a piece of burlap cannot be picked up intact after one to two months' exposure. The results of the most recent examination, taken in September, 1953, show no apparent deterioration after being exposed for a period of four years.

A word of caution should be stated regarding the interpretation of the above observations. Even though the material shows excellent resistance to bacterial action present in soil, deterioration from other causes may be of major concern.

Field observations indicate that the vinyl coating is palatable to rodents and insects. Since any removal of the vinyl binding reduces the strength of the glass fiber, steps should be taken by the manufacturer to render the product impalatable to rodents and insects.

TABLE 1. SUMMARY OF BURSTING-PRESSURE TESTS ON FIBRYLON IRRIGATOR FLEXIBLE PIPE
1950

Test No.	Bursting pressure, psi	Comments
		4½-in section with spiles (new)
1	12	Ruptured near coupling due to damage of material by previous coupling.
2	21	Break occurred away from the spile in the main section of the pipe.
		7½-in section with spiles (Tested previously, hence some tendency for previous damage)
1	15.5	Break occurred at a small hole in the main section of the pipe away from the spiles.
2	12	Break occurred on the under side of the pipe making it impossible to observe the cause of the break; however, a small hole on the top side of the break did not rupture at 12 psi.
3	18	Break occurred in main section of pipe where no previous damage had been observed in the fabric.
4	25	Break occurred in main section of the pipe. Near the location of the break several points of near rupture were apparent from observation of the fabric around the hole after the rupture occurred.
		7½-in section without spiles (new)
1	No rupture	Pipe did not rupture at 19 psi sustained pressure. However, at this pressure a metal clamp used on the spiles was moved along the spile by the pressure. As the clamp moved the spile was scraped causing some surface damage to the fabric. This bruised spot only withstood 8 psi during a later test. It apears that scratches weaken the pipe considerably. At very low pressures (up to 6 psi) this may not be so serious.
2	22.5	Rupture occurred at connection with metal union.
3	22.7	Rupture occurred along seam.

The material also appears to be readily susceptable to mechanical injury from ordinary field use.

Bursting Pressure Determinations

A summary of the bursting pressure tests is shown in Table 1. For all of the tests the pressure was applied over a relatively short period, so that the results are not necessarily indicative of the pressures which the pipe would sustain if maintained at a given pressure over a long period.

From the comments opposite each test, it will be noted that the pipe can be expected to withstand a pressure of approximately 20 psi over a relatively short period providing the pipe is not damaged in any manner. Surface damage to the fabric materially reduces the bursting pressure. An early bursting pressure test(not shown in the table) was made on the 7½-in section with spiles when the pipe was first received. In the new condition the section withstood a pressure of better than 20 psi. However, it will be noted from the table that this same pipe withstood considerably less pressure after it had been subjected to handling. It is interesting to note that in general the ruptures did not seem to originate at the spiles nor at the seams. Often the break began at a small hole, scratch, or some other defect in the material.

Control and Measurement of the Flow from Spiles

The spiles with the drawstring controls were tested in the field under actual irrigation practice. For higher pressures, it was necessary to fold the spile before tying it in order to stop the flow entirely. Once the knots became soaked, it was hard to adjust the flow by use of the strings. In general the drawstrings were not satisfactory. Because of these difficulties, a hinge type of control was developed as a substitute for the drawstrings. The control consisted essentially of a strap hinge with a bolt on the end. The spile was placed between the two leaves of the hinge. This device not only gave positive, easily adjustable control of the flow but could also be calibrated so that the distance between the ends of the hinge was proportional to the discharge at a given pressure. Furthermore, when the hinge was placed relatively near the point where the spile was attached to the main pipe, the balance of the spile served as a good energy dissipater, thus reducing to a minimum the erosion tendencies of the stream. In addition, the control is easily manufactured, inexpensive, and not bulky enough to seriously impede the flexibility and movement of the pipe.

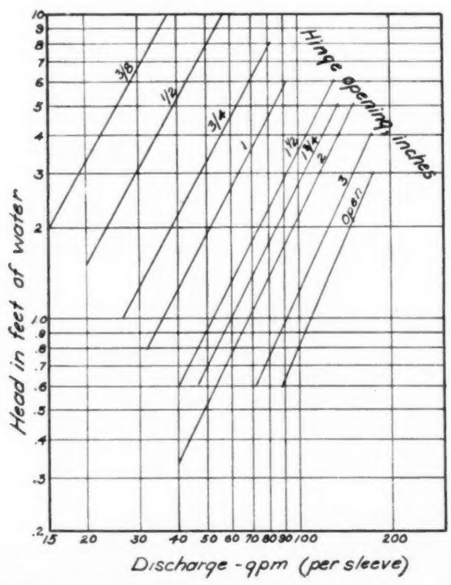


Fig. 1 Head-discharge curves for various hinge openings on 7½-in "Fibrylon Irrigator" flexible pipe with 3-in-diam discharge sleeves and 5-in strap hinge

Fig. 1 shows the head-discharge relationship for various hinge openings on 7½-in-diam flexible pipe having 3-in-diam spiles. The straight-line, systematic family of curves attest to the accuracy and utility of the hinge-type control. The curves lend themselves very readily to representation by the following common formula:

$$Q=CA\sqrt{h}$$

Hence the discharge can be readily determined from either graphs or formulas.

RECOMMENDATIONS FOR FUTURE STUDY

Not only should the presently conducted deterioration studies be continued, but in addition the materials should be subjected to other types of accelerated deterioration tests characteristic of such factors as heat, sunlight, and mechanical damage.

Further careful tests should be made under rapid as well as sustained pressures to determine the safe and recommended working pressure for the flexible pipe. These tests should be conducted on several sizes of the pipe with and without spiles.

Even though considerable progress has been made toward an accurate and dependable control for the spiles, further tests are needed before the hinge type of control can be released for general field use. For instance, the effect of the location of the hinge on the spiles should be more fully determined. The required strength of the hinge must be determined on the basis of the maximum pressures to be encountered. Furthermore, under high pressures the hinge tends to move or slide along the spile for which corrective measures must be developed.

Of utmost concern in the field application of this material is the carrying capacity of any given size pipe. The hydraulic characteristics are complicated considerably by the fact that the pipe is flexible resulting in a variable cross section. Recent research in the field of fluid mechanics gives very good clues as to the nature of the hydraulic characteristics, but specific tests must be conducted to completely solve the problem. Because of the nature of the pipe, it is not generally practical to tap it and install pressure gages to determine the piezometric head at a given location. However, the flexible nature of the pipe might be utilized very efficiently for this purpose in that the cross-sectional shape is a direct function of the pressure at a given cross section. Consequently it is possible that the cross-sectional shape would not only serve as an index of the flow to be expected from the spiles under a given opening, but when related between two sections would be indicative of the flow in the line.

The force required to cause a given deflection of the fabric might also be a practical index of the pressure. The utility of both the cross-sectional shape and the deflection should be fully determined. *(Continued on page 39)*

Field Performance and Maintenance of Deep-Well Turbine Pumps

Charles A. Lamb

THE advent of the deep-well turbine pump has made possible the development of many agricultural areas which depend on ground water for irrigation. Although the aggregate number of privately owned pumping installations represents sizable capital investment, the dispersion of these individual facilities has obscured facts that would allow the pump owners to make intelligent economic appraisals of the use and maintenance of their present, or proposed, pumping facilities. The purpose of this paper is to point out how prolonged field operation affects performance and maintenance of deep-well turbine pumps. These data are related to operating costs to establish a guide for achieving minimum water cost. An actual analysis is confined to a limited sample of pumps in a large California development; however, qualitative results and the method of analysis should be of general application to other areas.

The specific objectives of such an investigation are many. Some of the more significant items that would be of value in understanding the present picture and for extrapolating into the future are:

1 The loss in pump performance with sustained field operation

2 The average life of a pump

3 The point at which it is economically desirable to replace or repair a pump rather than continue operation at a low-performance level

4 Finding the reasons for physical deterioration of pumps in an effort to achieve remedial measures.

The present study followed the expedient measure of utilizing existing pump test data and repair histories. Pump test data were obtained from the Pacific Gas and Electric Company. These tests were originally made about twice a year as a service to the power consumers (Fig. 1). Tests were conducted with a good standard procedure; most test values should have an accuracy of within 1 or 2 percent with the maximum error probably not exceeding 3 or 4 percent. Test data were augmented by repair records obtained from pump companies in those cases where it was possible to trace the histories with certainty.

SAMPLE BACKGROUND AND SELECTION

Nineteen sample installations were selected from a total population of approximately 750 pumping units located on the west side of Fresno County in the San Joaquin Valley of California. This particular area was selected because of the severe pump duty and wear that has been encountered in the past. Wells and pumps within the area tended to be similar since the area was not large and there were no sizable demarcations in geographic conditions, either above or below ground level. A typical well might be 1500 to 2000 ft deep with a pump setting of 400 ft, or more, below the ground level. To achieve pumping heads of 400 ft with well drawdown, the pumps must consist of from 15 to 20 stages. All pumps are of the oil-lubricated type, as shown in Fig. 2, and most of them are driven by induction motors with full load speeds of 1160 rpm and power ratings of 150 to 250 hp.

Because of the year-'round growing season and the sizable investment in each pump and well, most of the pumps are operated almost continuously. A spot check of a dozen pumps indicated a spread of from 60 to 92 percent load factor, the average pump being run about 70 percent of the total elapsed time during a year.

The specific sample installations were selected at random from those pumping facilities that have a sufficient length of test records to make them appear usable for analysis. Approximately half of the total 750 population had histories approaching, or more, than ten years and could be defined as usable. Nineteen sample installations were selected; these yielded 45 separate pump replacements or pump rebuilds that resulted in the equivalent of a new pump.

PUMP PERFORMANCE LOSS

The first evaluation of a field pump would logically be to compare its performance with the predicted field values based on laboratory tests of new pumps. Pump company laboratory performance curves were corrected for column and bearing losses, by accepted standard procedure (1)*, to obtain the predicted performance curves of the new pump. Fig. 3 shows a set of those curves with actual field test points superimposed to show the effect of prolonged operation. This figure is typical of eight such comparisons that were made. Several were a bit more erratic, but the essential features were similar:

1 A new pump ran close to predicted performance. In general the difference did not exceed field test accuracy.

2 As a pump aged the electric horsepower consumed remained constant, following a flat horsepower curve. Therefore, no safety factor on motor sizing was necessary to allow for wear.

3 Pumping heads throughout a pump life remained relatively

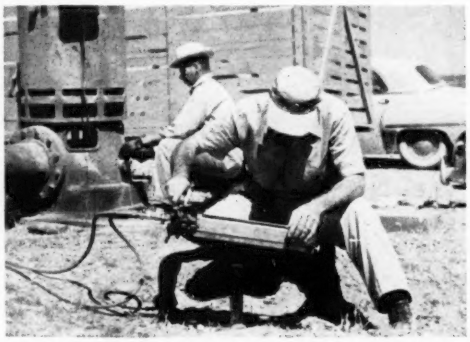


Fig. 1 A pump test crew in action. The man in the foreground is reading the discharge manometer while the other is lowering the sounding line

This paper was presented at a meeting of the Pacific Coast Section of the American Society of Agricultural Engineers at San Luis Obispo, Calif., February, 1953. The paper is based on the author's thesis for an advanced degree at the University of California.

The author—CHARLES A. LAMB—is a hydraulic engineer in the research and development center of the Kimberly-Clark Corp., Neenah, Wis.

*Numbers in parentheses refer to the appended references.

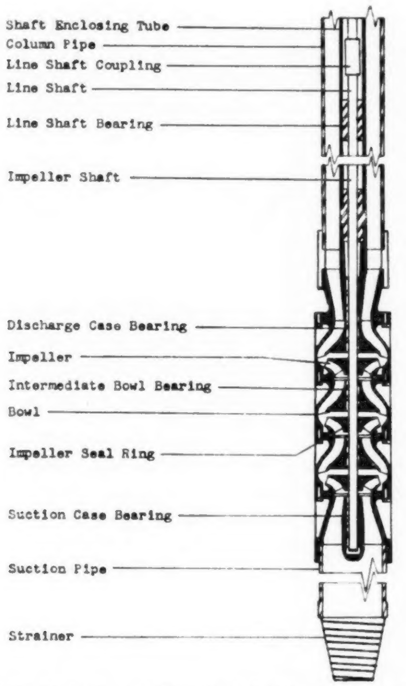


Fig. 2 Drawing of an oil-lubricated deep-well turbine pump. The number of stages is dictated by the total pumping head; each stage contributes 20 to 25 ft of water head. Pump discharges run to 1,500 gpm

constant as compared to pump discharge.

4 The pump discharge and pumping efficiency dropped in proportion to each other as a pump became more worn, since the horsepower consumed and the operating head were approximately constant.

5 A new pump was always sized so that its initial "operating point" was to the right side of the pump's efficiency hill. Thus, as the pump lost discharge during its life, it was still operating in a region where the efficiency should have been favorable and almost constant. Because of this an aging pump did not obtain obsolescence because it was poorly sized and was operating way to the left of its better efficiency region.

Note that there is every indication that the present practice of pump sizing proves adequate.

For the purpose of this study, the general pattern of pump performance change results in a simple convenient means of presenting results. Loss in pump discharge, which is of immediate interest to the pump user, is proportional to loss in efficiency, which is a general way of expressing decreasing pump performance. Furthermore, the actual efficiency changes are synonymous with efficiency drops due to pump wear rather than sizing obsolescence. Some plots of pump efficiency vs. life of the pump are shown in Figs. 4 and 5. The first test for each pump life does not necessarily indicate the exact time of pump start-up, nor does the last indicate its removal. Test dates were used as reference dates because the procedure of extrapolating these erratic curve[illegible]ld be somewhat questionable. The actual pump replacement date could be accurately established in only about one-third of the cases, although it could usually be estimated within one or two months.

Since the efficiency time curves of the pumps were all of different length and were of extremely varied shapes, there was some difficulty in finding the best way of averaging their characteristics. Since the efficiency of a new pump could be closely predicted, it was the rate of efficiency drop after the first test that was of principal interest. Curves of pump efficiency vs. pump life were plotted for each pump along with straight lines having slopes of 2, 4, 6, etc., percent drop per year — all starting at a common zero ordinate. Each curve was classified as to the segment in which it spent the greatest part of its life; or the medium segment if the pump spent significant time in three or more segments. This means of classification preserved the proper order of magnitude of the total loss pumpage during the life of the pump.

The total classification statistics for the 45 lives are shown in Fig. 6. The average efficiency drop was found to be approximated by a straight line with a slope of 7 percent efficiency drop per year within the lives of the pumps.

PUMP LIVES BETWEEN REPLACEMENTS OR REBUILDS

The aggregate statistics of pump lives are represented in Fig. 7. For consistency with the previous efficiency-time

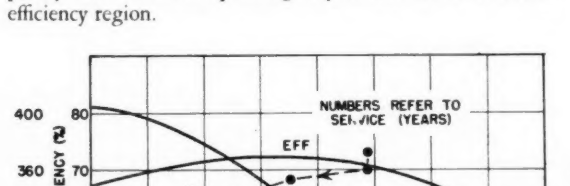
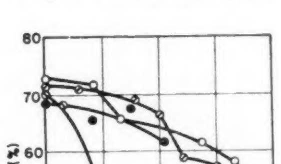


Fig. 3 Series of field tests shown on predicted pump performance curves (installation 9, pump number 3). The performance of this particular pump held up a little better than average



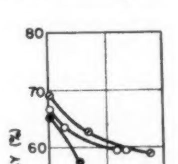


Fig. 4 *(Left)* Pump efficiency vs. years of service (pumps from installation 3) • Fig. 5 *(Right)* Pump efficiency vs. years of service (pumps from installation 4)

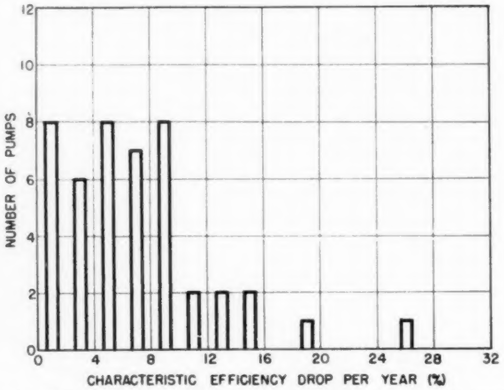


Fig. 6 Distribution graph of the rate of efficiency loss of the sample pumps. The average efficiency loss is 7 percent per year

curves, the plotted points are based on lives defined by first and last test dates. A better estimate of true life was obtained by adjusting for the operating time that occurred before the first test and after the last test. This correction puts the average life at 2½ years as opposed to an admittedly conservative value of two years. The corrected survivor and frequency curves, with an average life of 2½ years, are shown in Fig. 8 in dimensionless form.

The characteristics of these curves are typical of agricultural equipment (2). The primary distinguishing features are that the maximum frequency of retirement occurs before the pumps reach average life and that the frequency curve covers a broad area. The broader the frequency curve, the less is the probability that a single unit will adhere closely to the average life of the group. In contrast to the present case, properties such as railroad ties and box cars have a narrow frequency curve with a much smaller percentage of deviates from the average life of the group.

The probable error between the average life of the sample and the average life of the entire population of 750 installations was found to be 2.5 months.

A dependency of pump life on its efficiency loss may have been surmised from the previous material; the actual relationship is shown in Fig. 9. A correlation coefficient of 0.64 demonstrates a significant bearing of efficiency drop, or effects associated with efficiency drop, on pump life. (A correlation coefficient of one is perfect correlation; zero is no correlation.) There are numerous reasons for the scatter of the points. The ordinate values of efficiency drop were

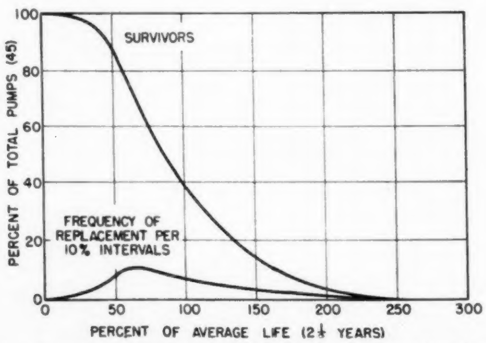


Fig. 8 Survivor and frequency of replacement curves based on corrected pump lives and shown in dimensional form

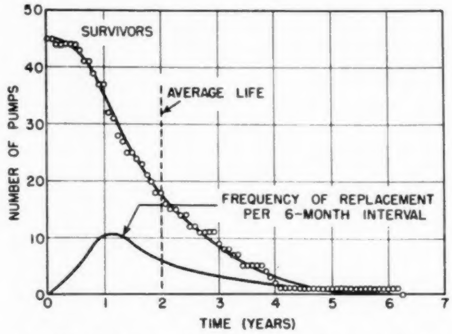


Fig. 7 Survivor and frequency of replacement curves based on pump test dates. Test dates usually underestimate the life of a pump by several months because a pump operates for a time before the first test and also after the last test

of an approximating nature and their precision would be no better than the next closest interval of 2 percent per year. ;A second major reason for scatter would be variations in individual owners response as to how serious the pump condition is. An owner might replace a pump six months or more prematurely merely for security of water supply during an anticipated season of heavy water demand. The opposite case would also be quite probable. Actual mechanical failure could also terminate a pump life at any time; however, the records gave no information that would establish the frequency of such occurrences.

REASONS FOR EFFICIENCY LOSS

In the preceding paragraph it was shown that pump life had a significant correlation with efficiency loss. It is desirable to go one step further and discuss the reasons for the pump efficiency loss. Examination of old pump parts and repair records indicated that worn impellers and pump bowls gave ample reasons for loss in pump performance (See Figs. 10 and 11). The local regions of greatest wear on pump impellers and bowls occurred at those points where the dynamic action of the pumped water would impinge foreign particles of sand or dirt. Scouring action was also evidenced in areas of close clearance between moving parts of the pump.

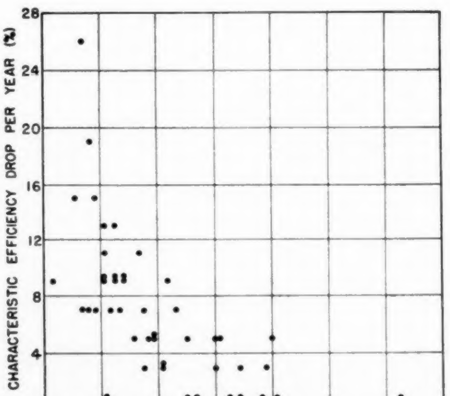


Fig. 9 Correlation of pump life with rate of efficiency loss

Consideration of the available repair records indicated that the extent of pump replacements, or rebuilds, alternated almost equally between two cases:

1 Replacement of practically all of the pump parts shown in Fig. 1 except the pump bowls. Some work on the pump column bearings and other parts was usually done.

2 Repairs that called for essentially complete bowl replacement as well as the above items.

These repairs included most of the expense of maintaining a pumping installation since work on the motor and electrical equipment was not frequent nor extensive. Insofar as it was possible to compare efficiency, there was no good reason to suspect that pump rebuilds resulted in anything less than the equivalent of a new pump.

In an attempt to isolate cause and effect, the uniformity of pump histories within individual wells was compared to uniformity between wells. The reasoning here was that significant variables that could be assigned to variations in well construction or conditions, such as sand size and availability, might remain somewhat constant for any one well. If conditions peculiar to individual wells had a greater influence on pump efficiency or life than variables that might be characteristic of the various pumps, all of the pump histories from any one well would be similar. Hence, most of the spread in the frequency curve of Fig. 7 would be due to variations from well to well. Using the proper statistical procedure (3), it was found that 25 percent of the variance in pump life is attributable to differences between wells. (If all 45 pump lives were obtained from one average well, the variance, or spread, of the frequency curve would be 75 percent of what is shown in Fig. 7). Since the variance attributable to the wells was not great and could have occurred simply by chance, its statistical significance was checked. It was found that there was only an 8 percent chance that wells had not affected pump life.

The net conclusion is that individual wells probably affect pump life but this effect is not great. The effect of wells on efficiency loss was the same order of magnitude; this could be expected since pump life correlated with efficiency loss.

ECONOMIC ASPECTS OF REPLACEMENT TIMING

All of the previous statistics have dealt with pump histories and replacement practices as they have existed to the present time. It cannot be assumed that past replacement practices have necessarily been the best for the pump user. If a pump suffers a complete mechanical failure, there is no question as to whether or not it should be replaced. If a runable pump is replaced because of its poor performance there should be economic justification for its replacement.

The general procedure for answering the above question can be set up quite readily. The item one desires to know is at what time in a pump's life has the average cost per gallon of water reached a minimum value. Since it has been shown that *(a)* the rate of pump efficiency loss can be approximated by a straight line, *(b)* discharge drops directly with efficiency, and *(c)* power input is constant, the following expression can be obtained:

$$\text{Average cost per gallon} = \frac{\text{total dollars}}{\text{total discharge}}$$

$$= \frac{C_1\, t + C_2}{(\text{initial discharge}) \times (t - C_3\,[t^2/2])}$$

where t = time (years)

C_1 = power cost per year plus depreciation and interest charges for entire pumping installation per year

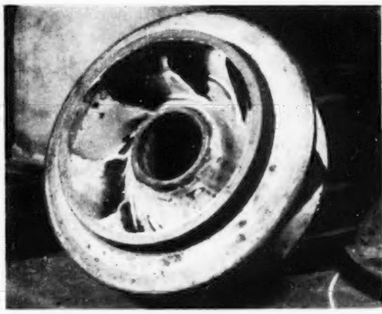
C_2 = repair cost

$$C_3 = \frac{\text{discharge loss per year}}{\text{initial discharge}} = \frac{\text{efficiency drop per year}}{\text{initial efficiency}}$$

Differentiating the above equation and setting it equal to zero to find the time for the minimum water cost,

$$-\frac{1}{2}\frac{C_1}{C_2}\,t^2 + t - \frac{1}{C_3} = 0$$

This expression is plotted in Fig. 12. The curves are of general application to any pump and are not subject to obsolescence



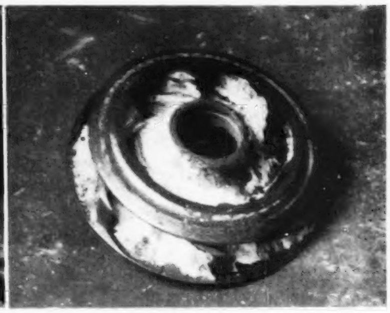


Fig. 10 *(Left)* Moderate impeller wear. Note that the once streamlined leading edges of the vanes have become quite blunt and irregular • Fig. 11 *(Right)* Severe impeller wear. The light areas are that portion of the original enamel coating that is still intact. Note that the suction side of the impeller, which runs close to the seal ring, is badly worn. The poor condition of the leading and trailing edges of the vanes can also be seen

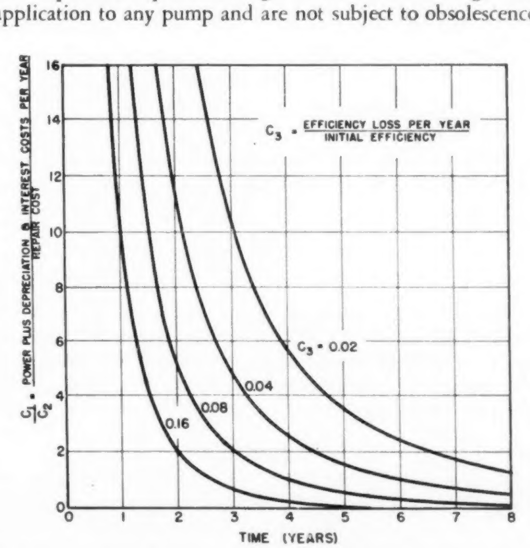


Fig. 12 Graph to determine optimum pump replacement time based on economic considerations

because of changing dollar values. It is only necessary to have sufficient pump tests to determine C_3 and adequate accounting information to establish contemporary values for C_1 and C_2.

All of the costs can be easily found or estimated except perhaps the depreciation or amortization of the original investment. There are various ways of arriving at this yearly cost (4). Without going into lengthy details, the author suggests the following equation as fairly representing the yearly cost applicable to this case:

$$\text{Annual depreciation and interest} = \frac{\text{Total installation cost}}{\text{Present value of one per annum}}$$

where the numerator depends on the expected life of the installation and a nominal interest rate for the investment funds [numerator values can be found in books such as reference (5)].

This cost is dependent on expected life of the installation and indicates that specific data in this regard would be highly desirable. The appropriate interest rate depends somewhat on the particular circumstances of the individual owners.

By assigning specific contemporary cost values to a representative pump from the sample group, it is possible to test pump-replacement practices to see if they are commensurate with optimum pumping economy. For a typical pump with a 2,000-ft well, a 150-hp motor, and operating 70 percent of the time, the following cost estimates are applicable:

Cost of entire installation including well, pump, and motor with starting equipment $44,000
Average repair cost 2,500
Annual power cost 5,620

Assuming an installation life of ten years and an interest rate of 5 percent,

Annual depreciation and interest $5,700

(The author feels that the ten-year life estimate is of the proper order of magnitude although there is no factual verification of its reliability. If in error, this estimate is probably on the low side.)

$$\text{Now } \frac{C_1}{C_2} = \frac{5{,}620 + 5{,}700}{2{,}500} = 4.53$$

The efficiency of a new pump would be between 70 and 75 percent and the average pump lost 7 percent efficiency per year, so

$$C_3 = \frac{0.07}{0.72} = 0.097$$

From Fig. 12 the optimum time for pump repair is 1.9 years. This value of optimum replacement time, which is based on present cost estimates, compares favorably with the average replacement time which was determined by past pump histories.

USE OF RESULTS

Two separate ideas have been expressed in regard to pump life. One presented past histories of pump performance loss and pump life. By an independent procedure it was shown that for any specific set of cost figures and rate of pump efficiency loss, there was an optimum time for pump replacement to achieve minimum water cost. Since for the average pump, the past pump histories were commensurate with the optimum replacement time based on present costs, they do not give conflicting values for predicting future pump life and average level of performance. If the past histories and optimum economic replacement time differed, prediction of the future would necessitate a compromise between the two. The future replacement program should attempt to follow optimum replacement time, however, there may be presently unassignable reasons, such as mechanical failure, why this could not be achieved. A practical way of predicting the future of a group of pumps would be to base it on past histories but also note, and try to achieve, the possible improvement that might result from replacing pumps at optimum replacement time.

Predicting the future history of an individual pump is quite uncertain because individuals can differ appreciably from the average. Once a pump has been in service for a year or so, its rate of efficiency drop aids considerably in indicating the approximate life that may be expected. Even with this approximate indication, individual pumps must be observed with diligence because efficiency trends are found to be subject to pronounced changes during a pump's life. Regular tests at about six-month intervals are adequate for checking most of the pumps. Those few that exhibit rapid losses in performance, either from the first couple pump tests or from observations of pump operation and discharge, warrant additional tests if a period of heavy water demand is anticipated.

The procedure used to develop the optimum pump-replacement time considered pumping costs as a separate operating cost which should be kept to a minimum. The possible agricultural income that might be attributable to the water supply was not considered. In view of this fact there are unusual circumstances that might warrant discounting the optimum replacement time, to some extent, in order to achieve a greater income from the entire agricultural operation. As an example, the necessity of having a great deal of water to meet unusually high water demands might warrant higher water costs to obtain greater income. If, however, an owner finds he is consistently in this particular "unusual" circumstance, the conclusion can only be that he does not have a sufficient number of wells to operate them most economically. Special cases do not nullify the value of the optimum replacement time idea but they do point out that economic analysis of individual facilities must be considered as they affect the over-all agricultural operation.

While the material presented in this paper is primarily concerned with achieving greatest economic benefit from present pump designs and well construction, it should not be implied that these are to be considered beyond improvement. The sample studied was from a fairly homogeneous group and, within the limits of the data available, there were insufficient distinguishing details for classifying wells or pumps in regard to which physical features might be preferable.

SUMMARY AND CONCLUSIONS

This paper presents a sample analysis of the life histories of 19 pumping installations selected from a total population of approximately 750 units. The parent area consisted of the west side of Fresno County in the San Joaquin Valley; pump duty and wear in this area are very severe.

The principal items of interest pertaining to the past histories of these deep-well turbine pumps were as follows:

1 The present practice of pump sizing is good and the performance of a new pump can be predicted within several percent.

2 Pump wear, occasioned by prolonged field operation, was evidenced by pump discharge and pump efficiency decreasing almost in direct proportion.

3 The average loss in pump efficiency with time in operation could be approximated by a straight line of 7 percent efficiency drop per year. In some individual cases the efficiency loss was almost negligible; in others the drop was two to three times the average rate.

4 The average life of a pump before a major repair, or a replacement, was close to 2½ years. The life of individual pumps varied considerably from the average.

5 The pumps and wells were quite homogenous and, within the limits of the available records, there were insufficient details to ascertain which specific pump or well features gave better performance. It was shown that conditions peculiar to individual wells affected pump wear and life, but this was not a paramount effect.

By considering the costs attributable to any pumping installation and the rate at which the pump's performance was decreasing, it was shown that there was an optimum time for pump repair, or replacement, to achieve minimum water cost. For an average pump this optimum time was commensurate with past replacement practices. This economic evaluation could be faciliated by better estimates of well life, and it is recommended that future work be concerned with this item.

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Flexible Irrigation Pipe

(Continued from page 33)

There is considerable opportunity for a very substantial contribution to the general field of hydraulics by a careful, well-planned study of the hydraulic characteristics of this flexible pipe.

Recommended Experimental Procedure

The bursting pressure as well as the spile control and cross-sectional shape studies could all be conducted with the same experimental equipment. Consequently, it is recommended that these three studies be undertaken as a unit.

Before the general hydraulic characteristics of the flow could be determined, the cross-sectional shape must be fully analyzed. Once this was done the general flow characteristics could be related to the change in cross-sectional shape from point to point. Hence this latter study is not only dependent upon the conclusion of the first phase for its successful prosecution, but also requires additional experimental equipment.

For the above reasons, it is recommended that the deterioration tests be conducted similtaneously with the two hydraulic phases. The first hydraulic phase to be studied would be the bursting pressure, spile control, and cross-sectional shape, to be followed by the second phase consisting of a detailed study of the hydraulic characteristics in terms of the change in cross-sectional shape between two points in the main line.

Culverts for Measuring Runoff

(Continued from page 31)

Weir sill layout dimensions for an 8-ft culvert width are shown in Table 1. All dimensions are in inches.

TABLE 1. LAYOUT DIMENSIONS FOR WEIR SILLS
(Culvert width = 8 ft)

Crest length, L	X_1	Y_1	X_2	Y_2	X_3	Y_3	X_4	Y_4	Crest radius
64.80	35.88	30.93	28.42	21.84	5.95	17.54	7.52	15.63	3.00

The layout dimensions for culverts of other widths can be obtained from the above table by applying simple proportion, since the culverts are geometrically similar. It should be noted that the dimensions shown are those required after the weir sill is in place in the culvert. Therefore these dimensions should be reduced approximately ½ in to allow for a mortar layer between the sill and the culvert.

Performance. The experimental weir sills have been in place over a year and have proved quite satisfactory. They have not been displaced nor have they cracked. Although the sills have caused some additional deposition to take place on the culvert apron because of lower approach velocity, the weir sill throat has remained clean.

SUMMARY

The principal findings of this research can be summarized as follows:

1 The rectangular highway culvert can be used for a flow-rate measuring device if it flows part full and with free outfall.

2 The use of a Villemonte-type weir sill can improve the accuracy of the measurement in the low-flow range.

3 A standardized weir sill has been developed with all dimensions proportional to the width of the culvert in which it is placed.

4 A satisfactory location for the weir sill has been found to be with the throat a distance from the culvert entrance equal to one and one-half times the width.

5 The head-discharge relationship for various culverts equipped with weir sills has been determined by hydraulic model experiment.

6 Methods of layout, construction, and installation of weir sills in rectangular highway culverts are given.

7 The prefabricated concrete weir sills installed in highway culverts have been proved quite satisfactory by field tests.

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INSTRUMENT NEWS

KARL NORRIS, Editor

Sponsored by the ASAE Committee on Instrumentation and Controls. Contributions on agricultural applications of instruments and controls and related problems are invited, and should be submitted direct to K. H. Norris, Agricultural Research Center, Beltsville, Md.

Cyclic Temperature Regulator

J. G. Kemp and F. D. Cook
ASSOC. MEMBER ASAE

IN connection with studies on the effect of temperature on rate of nitrate accumulation in soils, a cyclic temperature regulator was designed and constructed to simulate the typical diurnal temperature change in soil. The construction and use of this regulator is described for the benefit of those wishing to use a fluctuating incubation temperature.

The basic unit consisted of a standard household refrigerator into which a temperature control unit was placed. This type of unit is supplied by scientific equipment companies for modifying regular refrigerators for B.O.D. research. The detachable control unit was modified to give the results desired. Fig. 1A shows a graph of the daily soil temperature at Swift Current, Sask., for a typical week during fine weather. The curve is somewhat similar to that of a sine or simple harmonic motion curve. Actually the cycle is not symmetric in that the ascent takes place in a shorter time than the descent. However, because of simplicity of construction it was decided that a regulator producing a simple harmonic motion curve would suffice for our immediate needs.

A 24-hr Foxboro clock (1) as shown in Fig. 2 was used as a power unit. A sliding-crank arrangement (2) gave the simple harmonic motion. The drive pin (3) for the sliding crank was fixed to a flat disk (4) on the drive stem of the clock. A gear rack (5), which served as a crank rod, was made to drive a pinion gear (6) which replaced the control knob on the thermoregulator (7). The throw of the crank and the diameter of the pinion gear were calculated to give a temperature difference of 15 deg. The throw of the crank can be adjusted by means of a slotted radial hole (8) in the disk for the drive pin for the sliding crank.

The resulting temperature cycle produced by the mechanism is shown in Fig. 1B. The temperature difference can be decreased or increased by adjustment of the crank throw. The temperature range desired is selected by trial and error by preliminary setting of the thermoregulator. The temperature difference as shown in Fig. 1B is 15 to 16 deg ranging between 42 and 58 F.

It is an easy matter to modify the apparatus to duplicate any curve by construction of a cam or linkage to replace the circular disk and sliding crank. Instructions for designing such mechanisms are described by R. M. Keown and V. M. Faires in their book "Mechanism" (third edition) published by McGraw-Hill, New York.

The authors — J. G. KEMP and F. D. COOK — are agricultural research officers of the engineering section and soil research laboratory, respectively, Dominion Experimental Station, Swift Current, Sask.

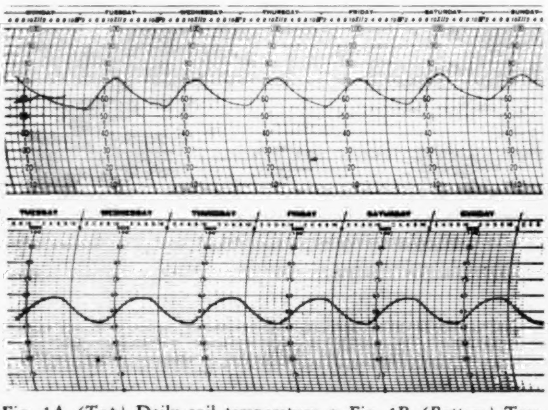

Fig. 1A *(Top)* Daily soil temperature • Fig. 1B *(Bottom)* Temperature cycle produced by the temperature control regulator

Research Problems

JUST to eat as well as we are eating today, the people in 1960 will need about 2 billion pounds more meat, a half billion dozen more eggs, about 5 billion pounds more whole milk, and we will need to use several hundred million more bushels of feed grains. There will be corresponding increases in requirements for fruits, vegetables, and other foods.

I hope that in 1960 we will be eating better – that our nutrition level will be higher–than today. If so, the requirements, especially for animal proteins and other protective foods, will be quite a bit higher.

But that's six years away, someone may say. We've got to worry about today.

I recognize the immensity of the problems today. Right now farmers are concerned about surpluses. The surplus problem is being given much thought, and the answer is likely to involve a number of different actions.

There's one point, however, on which we can be sure. Whatever the final decisions, research can make a contribution. But in research we have to continue looking ahead, and govern our activities accordingly.—Byron T. Shaw, before the 8th National Farm Electrification Conference, Washington, D.C., October 27, 1953.

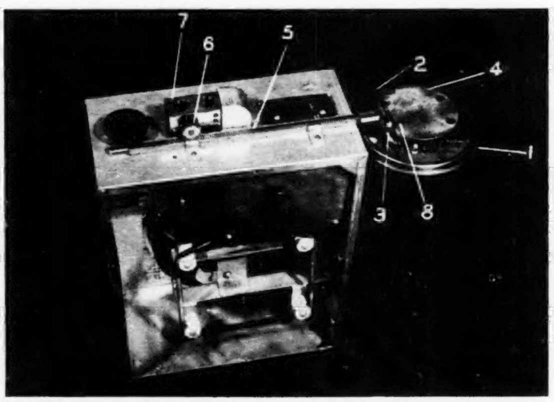

Fig. 2 Component parts of temperature-control regulator

NEWS SECTION

Nominations Announced for 1954-55 ASAE Officers

THE Nominating Committee of the American Society of Agricultural Engineers—E. G. McKibben (chairman), R. H. Driftmier, and R. R. Poynor—has nominated the following members for elective offices to be filled at the next regular election of officers. Voting will be by letter ballot, which will be mailed to members in February. Closure of voting will be March 31. Vacancies to be filled are those anticipated by expirations of terms of office at the time of the annual meeting in June.

NOMINEE FOR PRESIDENT

George B. Nutt was born and reared in Mississippi and received his bachelor's degree in agricultural engineering at Mississippi State College in 1930. After an additional two years of industrial training with the International Harvester Co., he went to

GEO. B. NUTT

Clemson Agricultural College as associate professor of agricultural engineering. For several months in 1936 he served as farm representative in North and South Carolina for the Federal Housing Administration, but returned to his position at Clemson on completion of that assignment. During these years he also completed requirements for a master's degree in agricultural engineering awarded him at Iowa State College in 1940.

In July, 1941, he was promoted to professor and head of the agricultural engineering department at Clemson, and has continued in that position with the exception of brief periods on special assignments. For most of 1944 he was loaned to the U.S. Department of Agriculture Office of Foreign Agricultural Relations for work as senior agricultural engineer in charge of research and station development along agricultural engineering lines in cooperative experiment stations in Latin America. As consultant to the International Bank for Reconstruction and Development he studied conditions in Syria and Iraq in October and November, of 1950, and in Paraguay in August, 1951.

Elected to membership in the Society in 1932, he has served as chairman of the agricultural engineering teaching seminar, as vice-chairman and chairman of the College Division, chairman of the Southeast Section, ASAE representative on the ECPD Accrediting Committee for the Southeast area, and member of Committees on Fertilizer Application, Standards, and Student Paper Awards, and on the Nominating Committee.

Among other activities, he is vice-chairman of the National Joint Committee on Fertilizer Application, a member of the American Society for Engineering Education, member of the Pickens County Board of Trustees, a director of the Fort Hill Building and Loan Association; member of Alpha Zeta and of the Clemson Fellowship Club, and honorary member of Blue Key. He is listed in "Who's Who in the South and Southwest."

NOMINEES FOR VICE-PRESIDENT

Harold H. Beaty is a product of Iowa. After earning a bachelor's degree in electrical engineering at Iowa State College in 1931, he started his professional career with the Iowa Electric Company, with work on meter testing, sales engineering, and public relations. In 1934 he entered the employment of the U.S. Department of Agriculture for work in Iowa as agent in charge of field work and crew supervisor on white pine blister rust control.

This led to his appointment in 1936 as assistant extension agricultural engineer in Iowa, specializing in rural electrification. In the years following he worked for a master's degree in agricultural engineering, which was awarded in 1942 Iowa State College; earned promotion to assistant extension professor of agricultural engineering in 1945, and associate extension professor in 1946. In 1949 his duties were expanded to include research and work as collaborator on the staff of the division of farm electrification, U.S. Department of Agriculture. In 1950 he was named associate professor of agricultural engineering in charge of rural electrification at Iowa State College. The following year he was called to his present position as rural service manager of the Edison Electric Institute.

In addition to his broad experience in extension work, Mr. Beaty has been directly associated with research on various kinds of electric equipment for farm use. He also collaborated in outlining and organizing a senior level required course in farm electrification for students in the professional agricultural engineering curriculum at Iowa State.

A member of ASAE since 1937, he has been active in its Rural Electric Division, regularly serving on one or more of its committees, and contributing frequently to its meeting programs.

David B. Poor grew up on a farm near Warsaw, Indiana. After two and one-half years of study in engineering and agriculture at Purdue University he transferred to Iowa State College and graduated in agricultural engineering in 1939.

For the next two years he was at Racine, Wisconsin, with the Massey-Harris Co. From 1941 to 1945 he was in defense work as test engineer on Packard Rolls-Royce aircraft engines. After a year spent in putting his own farm in order, he became agricultural engineer in the Stran-Steel Division of Great Lakes Steel Corporation at Detroit. In that work he has been active in the development and application of steel construction for a variety of farm buildings and particularly construction for the storage, drying, and conditioning of grain.

A member of ASAE since 1939, he has been active in the Michigan Section in which he served as Chairman for the year 1950-51, and in the Farm Structures Division, serving first a year as vice-chairman followed by a year as chairman in 1952-53.

NOMINEES FOR COUNCILOR

Richard K. Frevert is a native of Iowa and earned his bachelor's degree in agricultural engineering at Iowa State College in 1937. Upon graduation he began teaching power and machinery courses in the agricultural engineering department as instructor,

ASAE Meetings Calendar

January 22 and 23 — PACIFIC COAST SECTION, Stockton, Calif.

January 22—IOWA-ILLINOIS SECTION, American Legion Club, East Moline, Ill.

January 22 and 23—NORTH CAROLINA SECTION, North Carolina State College, Raleigh

February 1-3—SOUTHEAST and SOUTHWEST SECTIONS, Baker Hotel, Dallas, Tex.

February 13 — MICHIGAN SECTION, Hotel Hayes, Jackson, Mich.

April 2 and 3 — ROCKY MOUNTAIN SECTION, Colorado A. and M. College, Fort Collins

June 20-23—47TH ANNUAL MEETING, University of Minnesota, Minneapolis

NOTE: Information on the above meetings, including copies of programs, etc., will be sent on request to ASAE, St. Joseph, Mich.

Nominees for Vice-President

D. B. POOR

H. H. BEATY

Nominees for Councilor

R. K. FREVERT

G. E. RYERSON

and held this position until he reported to the Armed Forces in 1942. In the meantime, he had received his master's degree in 1940, working on a tillage problem in the power and machinery field. After serving three years in the Army Air Force Weather Service, and being discharged at the rank of captain, he returned to Iowa State College as an assistant professor, and was in charge of the soil and water conservation courses and research in the agricultural engineering department. In 1948 he was promoted to associate professor and in 1949 to full professor. In 1952 he was named assistant director of the Agricultural Experiment Station and retained his status as a professor of agricultural engineering, currently spending about one-third of his time in the departmental activities.

Mr. Frevert has been author of several papers on various aspects of soil and water conservation and is senior author of the Ferguson Foundation text on soil and water conservation engineering, now in a prepublication edition and scheduled to be published by John Wiley and Sons early in 1955. He has served on several committees of the Society since becoming a member in 1938, and is now chairman of the Committee on Depth and Spacing of Tile Drains. He is a member of Alpha Zeta, Gamma Sigma Delta, Knights of St. Patrick, Phi Kappa Phi, and Sigma Xi honor societies. He is registered in Iowa as a professional agricultural engineer and is also a member of the Iowa Engineering Society, the Soil Conservation Society of America, and the American Geophysical Union.

Gerald E. Ryerson is a native of Ohio and an agricultural engineering graduate of Ohio State University in 1928. Following his graduation he was first associated with the corn borer control program, until 1931, when he transferred to erosion control work. He was assigned to the Upper Mississippi Valley Erosion Control Experiment Station for two years, then made project engineer for the first demonstration project in the area, at Coon Valley, Wis. Later in 1933 he was promoted to chief engineer in the Soil Conservation Service for Minnesota and Wisconsin. From 1936 to 1942 he served in Washington, D.C., as equipment engineer for the SCS. Called to active duty in 1942 in the Ordnance Department of the Army, he saw service at the Tank Automotive Center in Detroit, overseas duty in the South Pacific, and a tour in the office of the Chief of Ordnance, with promotions to the rank of major.

Returning to the Soil Conservation Service in 1946, he was designated as farm equipment research specialist and equipment engineer, and assigned responsibility as liaison officer between the Service and the farm equipment industry. Since 1947 he has carried additional responsibility for cooperative work of the Service and the industry at the Pendleton, Ore., erosion experiment station.

A member of the Society since 1934, he has been active in both the Power and Machinery and the Soil and Water Divisions. He is past-chairman and member of the executive committee of the latter division, and also a member of the Steering Committee of the former.

ASAE Winter Meeting

STRONG interest in the program was evident at the Winter Meeting of the American Society of Agricultural Engineers, December 7-9, at the Edgewater Beach Hotel in Chicago. At times during the technical sessions the connecting corridors were practically deserted. The published program was closely followed and will not be reported here in detail.

Early arrivals for the Sunday afternoon Cabinet meeting and registration and the entertainment Sunday evening were numerous and exceeded those of previous years.

Section representatives reported and compared notes on their activities during the Cabinet meeting. Their interest and enthusiasm, and the range of successful Section activities reported, emphasized the importance of the Sections as pillars of strength in the Society.

Strong interest in worldwide agricultural engineering progress was reflected in attendance at the Sunday evening illustrated lecture by Robert L. Green on agricultural practices in Indonesia. It filled the East Lounge to the "standing room only" condition.

Minnesota Section members were present in force with reminders that the Society's Annual Meeting in June will be held at Minneapolis. They showed well developed plans to make it worth attending from a technical and professional standpoint; and attractive as an opportunity for an interesting and budget-priced family outing. The Meetings Committee gave Division chairmen a clear picture of the general plan for the meeting and time available for technical sessions. Arrangements for additional annual meeting attractions were advanced while the Minnesota group were in Chicago.

In its round of meetings with its member organizations, 1953 was the year for the National Joint Committee on Fertilizer Application to get together with the Power and Machinery Division of the ASAE, as cosponsors of a fertilizer application program. Strong interest was shown in the program provided. In addition there was a renewing and strengthening of acquaintance between agricultural engineers and some of the leaders of agricultural science and trade associations cooperating in the work of the Joint Committee.

An address by H. B. Walker (past-president ASAE), professor emeritus of agricultural engineering, University of California, on "balancing agricultural engineering research," was the featured attraction of the dinner sponsored by the Research Committee of the Farm Equipment Institute for agricultural engineering research leaders in public service. From a lifelong background of service and leadership in this field he summarized the need, nature, extent and future of progress in agricultural engineering research, concluding his remarks with an appeal to research workers to further improve the quality of their research. His address drew a record attendance at the dinner.

Chicago Section representatives carried their usual major share of responsibility for local arrangements. Lee H. Ford, chairman, and Erwin R. Johnson were on duty at the registration desk and were assisted by Mr. and Mrs. Howard C. Rutt. Kenneth W. Snyder is credited with arrangements for having the Society represented on two live television shows, five live radio programs, and sixteen transcriptions for later radio broadcasting, in the interest of favorable public relations. Mr. and Mrs. John H. Wessman worked with him on these arrangements and on releases to publications. C. F. Albrecht and D. P. Brown of Michigan State College, Keith L. Pfundstein of Ethyl Corp., and Chas. E. Ball of *Farm Journal* came in to lend a hand to the Chicago representatives of the Public Relations Committee. C. N. Hinkle, Standard Oil Co., contributed his usual yeoman service as official photographer.

Pressure for progress along a number of specific lines was evident in the number and variety of committee and special group meetings sandwiched in and around the scheduled division sessions. In addition to those listed on the printed program there were meetings of the Jury of Awards; ASAE committees on agricultural research conference, technical data, agricultural teacher training, course content, farm structures research, design and construction of tile drainage, heat lamps for brooding, public relations, and instrumentation and controls; steering committees of some of the divisions, and other special group gatherings.

K. W. (Ken) Westerberg *(left)*, wearing king-size badge promoting the 1954 ASAE annual meeting in Minnesota, regales K. W. (Ken) Anderson and ASAE President E. W. (Ed) Tanquary at the 1953 winter meeting of the Society in Chicago, not only on the wonders of Minnesota in general but obviously also on the size of the inhabitants of Minnesota's sky-blue waters

Oklahoma Section Elects Nelson

GORDON L. NELSON, associate professor of agricultural engineering, Oklahoma A & M College, was elected the new chairman of the Oklahoma Section of the American Society of Agricultural Engineers at the Section's annual meeting held November 20 at Stillwater. He succeeds W. T. Wheeler, regional product specialist, tillage and machinery sales, International Harvester Company.

The new vice-chairman of the Section is John Johns, supervisor of rural sales and

(Continued on page 44)

NEWS SECTION

(Continued from page 42)

service, Oklahoma Gas and Electric Co., and the new secretary-treasurer elected at the meeting is Fred R. Gray, construction engineer, Soil Conservation Service, USDA.

Fifty-one members and friends of the Section registered for the one-day meeting, which included a technical program along with the annual business meeting of the Section. The forenoon program included three papers, one on liquified petroleum gas as a farm tractor fuel presented by J. G. Porterfield, associate professor of agricultural engineering, OAMC, a second on the subject of domestic water systems for treating and using farm pond water presented by Elmer R. Daniel, assistant professor of agricultural engineering, OAMC, and a third on management of soils for conservation in western Oklahoma by H. H. Finnell of the Pan-Handle Experiment Station at Goodwell, Oklahoma.

The afternoon technical program opened with a paper by Richard Anderson on new and improved applications of Douglas fir plywood in farm structures. This was followed by a panel discussion on the development of farm irrigation systems for Oklahoma. C. V. Phagan, extension agricultural engineer, OAMC, presided as moderator for the panel which included also Van R. Wiggins, Robert B. Duffin, and James E. Gartin.

At its business session, the Section voted to hold its spring meeting at Clinton, Okla., where an opportunity will be provided to inspect a number of soil mechanics projects under way in connection with the watershed control work in that area.

Cornell Conferences on Pest Control

THE agricultural engineering department at Cornell University was cosponsor with the departments of plant pathology and entomology at Ithaca and at the agricultural experiment station at Geneva of pest control conferences held at Ithaca, November 10 to 12.

A combined program was offered by the 15th Annual Insecticide and Fungicide Conference and the 6th Annual Pesticide Application Equipment Conference. Host to the combined groups was the Cooperative GLF Exchange.

These annual conferences are held as a cooperative effort to report to the agricultural pesticide and application equipment industries on the recommendations for disease and insect control for the coming season and the highlights of the research of the current year upon which the recommendations are based.

Attention was given in the three day program to results of research with mist concentrate and low-gallonage sprays in comparison with high-gallonage equipment. Reports of research and recommendations for disease and insect control covered the fields of woody ornamentals, florist crops, turf crops, and forage crops. Extensive coverage was given to similar reports on potatoes, vegetable and fruit crops. Livestock insects and houseflies were discussed.

Representatives of the agricultural engineering department contributing to the program included O. C. French, who presided over the opening session, and W. W. Gunkel and E. D. Markwardt, who reported on developments in the application of concentrated and high-gallonage sprays for tomatoes and onions.

Total registration for the three days of the conferences reached 402. Representatives attended from 91 industries and 7 universities in the United States; 20 Canadian industries and institutions were represented by 51 people. Those attending came from 18 states, Canada and Hawaii. In keeping with established policy, no over-all report will be issued covering the work of the conferences.

NEWS OF ASAE MEMBERS

Byron T. Virtue, for some time chief engineer of the Bearings Division, The Torrington Co., Torrington, Conn., was recently promoted to the position of general sales manager. Mr. Virtue joined the Torrington organization in 1945 as research and development engineer, and shortly thereafter was made chief engineer of the Bearings Division.

B. T. VIRTUE

Mr. Virtue is a native of Iowa, and an agricultural-engineering graduate of Iowa State College where he received his bachelor's degree in 1931 and a master's degree in 1932. While in college he was engaged in his spare time in work for the agricultural engineering section of the Iowa Agricultural Experiment Station, much of which was devoted to building and testing experimental power-farming equipment being developed by the section. Later he was employed for several years as an extension specialist in agricultural engineering for the Iowa Agricultural Extension Service which included work in planning and conducting projects on farm machinery repair and adjustment and a variety of other agricultural-engineering activities.

Bernard P. Rines recently resigned as chairman of the agricultural engineering department at the University of New Hampshire to operate an agricultural engineering and contracting division of Walnut Crest (a family farm at Gorham, Maine). Activities include sales, service and manufacture of specialized farm equipment, and custom operation of forage harvesting equipment. His address is Westbrook, Me.

Calvin K. Mutchler has resigned his position in the agricultural engineering department at the University of Connecticut to accept a technical assignment with the B. F. Goodrich Co. His new address is 330 Hopocan Ave., E., Barberton, Ohio.

Eugene H. Dumm has been transferred by the International Harvester Company from managerial supervisor of forging operations at its Fort Wayne, Indiana, plant, to assistant service supervisor for the Fort Wayne district.

ASAE Research Committee Reports

A REPORT of the ASAE Farm Electrification Research Conference Committee to the Division of Farm Electrification, U.S. Department of Agriculture, has been prepared, based on its meeting at Beltsville, Md., October 29. The report commends the Division on its work in progress and urges additional attention to nine subjects believed to offer major promise for added effective use of electricity in agriculture. In part, the report reads as follows:

"If American agriculture is to solve its basic long-range needs, it must reduce costs, improve quality of its products and expand its markets. The proper approach to each of these needs is through research and education. Research projects carried on by the Division of Farm Electrification in cooperation with land-grant colleges and universities are continuing to improve efficiency, save labor, and lower the costs of production for the American farmer.

"In view of the need to improve efficiencies of production, reduce labor and thereby lower the cost of production, the Committee recommends that basic and fundamental electrical research projects that show promise of achieving these ends be given increased support, attention, and consideration.

"The Committee wishes to commend the Division on its continuing efforts to coordinate the federal research program with the various landgrant college experiment stations. The Committee also recognizes that the Division is actively cooperating with a number of commercial organizations and recommends that this cooperation be continued.

Recent figures indicate that nation-wide extension of electric service to American farmers is now 91 percent completed. These farmers have invested billions of dollars in electric farmstead wiring and electrical farm and home equipment. In recognition of the tremendous investment and the wide acceptance of electric service by farm people the committee, therefore, recommends that major attention be given to those projects that show the most promise of benefiting the largest possible number of farm people.

In this connection the Committee urges that increased emphasis be placed on the following projects:

1 Use of radio frequency to condition such farm crops as rice, corn, wheat and alfalfa, and to destroy insects, bacteria and other microorganisms.

2 Effect of radiant and electromagnetic radiation and fissionable materials on plants and animals.

3 Effect of environmental conditions on health and production of poultry and livestock and development of specifications of equipment and conditions which will bring about further improvements.

4 The development of electrically operated equipment as a substitute for manual means of handling feed and forage and in chore operations.

5 Mechanical refrigeration for storing on the farm perishable products that must otherwise be marketed at time of harvest with the resulting in-seasonal market surpluses and out of season shortages for the consumer.

6 Use of electric energy as a means of controlling or exterminating insects that damage crops such as, corn, cotton, tobacco and other crops.

7 Use of the heat pump to condition feed and forage for farm storage.

8 Make further study of the processing of hay and feeds by use of high temperature to prevent enzyme and mold action so that higher quality products will results.

9 Exploration of the processes of photosynthesis as it relates to the most efficient production of food and fiber.

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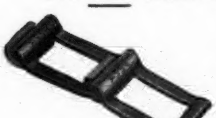

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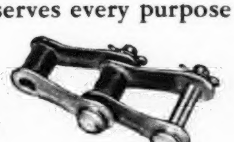

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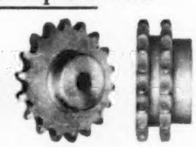

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Applicants for Membership

The following is a list of recent applicants for membership in the American Society of Agricultural Engineers. Members of the Society are urged to send information relative to applicants for consideration of the Council prior to election.

Anderson, David A. — Division engineer, J. I. Case Co., Rockford, Ill.

Bagley, Jay M. — Field engineer, Farm Improvement Co., 2045 S. Holly St., Denver, Colo.

Barefoot, Armond D.—Superintendent, agricultural experiment station, Oklahoma A. & M. College. (Mail) 116 W. Elm, Altus, Okla.

Beale, William S.—Manager, Gordon Edgell & Sons Ltd., Cowra, N.S.W., Australia. (Mail) PO Box 127

Birth, Gerald S.—Research engineer, agricultural engineering dept., Michigan State College, East Lansing, Mich.

Boving, Peter A.—Graduate student, University of California, Davis, Calif. (Mail) RR 1, Box 2

Campbell, Joseph K. — Engineer trainee, New Holland Machine Div., The Sperry Corp. (Mail) E. Main St., Belleville, Pa.

Carlson, C. W. — Manager, John Deere Spreader Works, 1209 13th Ave., East Moline, Ill.

Day, Douglas C.—2nd Lt., U.S.A.F. (Mail) Fly Creek, N. Y.

Dirksen, David P.—2nd Lt., U.S. Army. (Mail) 376 Meadow Drive, Rochester 18, New York

Elliott, Brantford G.—Project engineer, Harry Ferguson, Inc. (Mail) 621 N. Vermont, Royal Oak, Mich.

Every, Charles H.—Student, Michigan State College. (Mail) RR 1, Tecumseh, Mich.

Eyolfson, Donley D. — 2nd Lt., U.S.A.F. (Mail) 1414 Monroe St., Denver, Colo.

Flanagan, Vernon D. — Design engineer, Layne & Bowler Corp. (Mail) 15048 E. Starbuck, Whittier, Calif.

Floyd, Charles S.—Service supervisor, southwestern div., Minneapolis-Moline Co. (Mail) 510 W. Cherry St., Nevada, Mo.

Friday, William H.—Graduate student, Michigan State College, East Lansing, Mich. (Mail) 433 C. Hawthorn

Furry, Ronald B.—Instructor in agricultural engineering, Stocking Hall, Cornell University, Ithaca, N. Y.

Gibbel, Robert O.—College trainee, Caterpillar Tractor Co., Peoria, Ill. (Mail) 203 Cedar Ave.

Gockowski, Jerome A.—Engineer-in-training (SCS), USDA, Owatonna, Minn. (Mail) 139 W. McKinley St.

Griffin, William H., Jr.—U.S. Army. (Mail) RR 1, Thorsley, Ala.

Haddock, Donald J. — 2nd Lt., U.S.A.F., dept. of meteorology, Florida State University, Tallahassee, Fla.

Hay, Arthur C.—Process engineer, Anderson, Clayton & Co. (Mail) Western Cottonoil Co., PO Box 191, Lubbock, Tex.

Heffington, William E.—Agricultural engineer (SCS), USDA, Lonoke, Ark. (Mail) Box 135

Hennen, John J.—Student engineer, John Deere Ottumwa Works, Ottumwa, Iowa. (Mail) 1118 East 2nd St.

(Continued on page 48)

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Applicants for Membership

(Continued from page 46)

Henson, Clarence E., Jr.—Junior engineer, David Bradley Mfg. Works. (Mail) 1550 E. Chestnut, Kankakee, Ill.

Hibl, Joseph J.—Engineer trainee, The Timken Roller Bearing Co., Canton, Ohio. (Mail) 2112 Iris Ct. N.W.

Higginbotham, James A., Jr.—Agricultural engineer, The Ohio Tractor and Implement Co. (Mail) 460 Nellston St., Columbus 3, Ohio

Holt, Robert H., Jr.—Production trainee, Ralston Purina Co., Nashville, Tenn. (Mail) Apt. 10, Brookside Court Annex

Huddleston, Kenneth E.—Assistant to executive secretary, Farm Equipment Institute, 608 S. Dearborn St., Chicago, Ill.

Huntington, David H.—Assistant professor of agricultural engineering, University of Maine, Orono, Me.

Jenkins, Donald H. — Student, California State Polytechnic College, San Luis Obispo, Calif. (Mail) PO Box 1338

Johnson, Ernest A. — Agent (BPISAE), USDA. (Mail) Agricultural engineering dept., Purdue University, Lafayette, Ind.

Johnson, Roger F.—Field agricultural engineer, G.L.F. Northeast Area, 32 Champion Rd., New Hartford, N. Y.

Kinard, George P. — Assistant agricultural engineer, Clemson College, Clemson, S.C. (Mail) NBA 3

Klose, George L.—Trainee, Caterpillar Tractor Co., Peoria, Ill. (Mail) 303 Russell St.

Knox, Abba J.—District engineer (SCS), USDA, PO Box 1527, Haifa, Israel

Krohn, Robert L.—Ens., U.S. Navy, Naval Air Station, Pensacola, Fla.

Lawson, Lewis E. — Student, University of Nebraska, Lincoln, Nebr. (Mail) 1315 North 41st St.

Leslie, Wayne B.—Student, Oklahoma A. & M. College. (Mail) RR 3, Leedey, Okla.

McClure, Billy D. — Electrical development engineer, 4-County Electrical Power Assn., PO Drawer 827, Columbus, Miss.

McLean, Gordon L.—Sales trainee, Massey Harris Co., Fargo, N. D. (Mail) 1433 12th St. N.

Manwaring, Howard S.—Assistant director of engineering, International Harvester Co., Chicago, Ill. (Mail) Apt. 1017, 1360 Lake Shore Drive

Meinert, Harry M.—Junior product engineer, John Deere Planter Works of Deere & Co. (Mail) 208 E. 11th St., Davenport, Iowa

Merydith, Charles W.—Field representative, McDowell Mfg. Co., 301 Stanton Ave., Pittsburgh 9, Pa.

Moss, Nelson E.—Manager, irrigation dept., Farmers Mercantile Co., Salinas, Calif. (Mail) 245 Dororo Drive

Musick, Jack T.—Student and graduate assistant, Oklahoma A. & M. College, Stillwater, Okla. (Mail) E150 Bennett Hall

Ogle, Claude B., Jr.—Vice-president, Atlas Scraper and Engineering Co., 6203 Maywood Ave., Bell, Calif.

Olsofski, Matthew R. — Student engineer, John Deere Waterloo Tractor Works, Waterloo, Iowa. (Mail) 226 Leland Ave.

(Continued on page 50)

Accredited A-E Curriculums Reported

AGRICULTURAL engineering curriculums in 22 land-grant colleges and universities are now accredited by the Engineers' Council for Professional Development, according to the 21st annual report of that body for the year ending September 30, 1953.

Curriculums shown as accredited during and since the initial accrediting period in 1936-38, are those at Iowa State College, Kansas State College, and the University of Nebraska.

In the renewed accrediting activitiy since World War II, additional agricultural engineering curriculums accredited, by year of accrediting, are shown as, in 1949, University of California (curriculums at both Davis and Los Angeles) and Oregon State College; 1950, University of Idaho, University of Illinois, and University of Minnesota, Louisiana State University, Purdue University, Michigan State College, Oklahoma A & M College, A & M College of Texas, Utah State Agricultural College, and State College of Washington; 1951, Virginia Polytechnic Institute; 1952, University of Missouri and Rutgers University; 1953 Alabama Polytechnic Institute, Clemson Agricultural College, North Dakota Agricultural College, and West Virginia University.

Applicants for Membership

(Continued from page 48)

Opper, Lincoln I. – V-belt engineer, The Dayton Rubber Co., Dayton, Ohio

Pakala, George W.—Graduate fellow, department of agricultural engineering, Purdue University, West Lafayette, Ind. (Mail) 10-1 Ross-Ade Drive

Price, Louis W.—Power use advisor, Inland Empire Rural Electrification, Inc., Spokane, Wash. (Mail) N. 1911 Ely

Raney, John P.—Student, Purdue University. (Mail) 425 N. Broadway, Butler, Ind.

Rector, J. D.—Junior engineer, David Bradley Mfg. Works. (Mail) 545½ S. Cannon, West Kankakee, Ill.

Reed, Richard D.—Engineer, Krauss Heating and Ventilating Co., St. Petersburg, Fla. (Mail) 1416 40th Ave. North

Richardson, Harvey H.—2nd Lt., U.S. Air Reserve. (Mail) 716 W. Schaaf Rd., Cleveland 9, Ohio

Rush, Alvin P.—2nd Lt., U.S. Army. (Mail) Box 413, Student Officers Detachment, Aberdeen Proving Ground, Md.

Schaubert, Darwin J.—2nd Lt., U.S.A.F. (Mail) Bowdon, N. D.

Shropshire, David C., Jr.—Sales engineer, Ross Gear & Tool Co., Lafayette, Ind. (Mail) 2915 Greenbush St.

Soucek, Frank J., Jr.—Commercial representative, sales dept., Virginia Electric & Power Co. (Mail) Disputanta, Va.

Stafford, Darrell E.—2nd Lt., U.S. Army. (Mail) RR 2, Box 666, Grants Pass, Ore.

VanLiew, Kenneth E. – U.S. Air Reserve. (Mail) Union Springs, N. Y.

Williams, Robert L.—Agricultural engineer, Johns Equipment Co., Farmville, Va.

Wotring, Earnest H. – Power use adviser, Oklahoma Statewide Electric Cooperative, 2726 N. Oklahoma, Oklahoma City, Okla.

Zollars, Richard U.—Project engineer, John Deere Ottumwa Works, Ottumwa, Iowa. (Mail) 409 W. Maple St.

Transfer of Membership Grade

Colwick, Rex F.—Agricultural engineer, Regional Cotton Mechanization Project, Box 175, State College, Miss. (Associate Member to Member)

Gerard, E. D.—Instructor, dept. of agricultural engineering, California State Polytechnic College, San Luis Obispo, Calif. (Affiliate to Member)

Graham, Clyde W.—Flood prevention specialist (SCS), USDA. (Mail) PO Box 711, San Saba, Tex. (Associate Member to Member)

Kolega, John J.—Instructor in agricultural engineering, University of Connecticut, Storrs, Conn. (Affiliate to Associate Member)

Liu, Yong-Chi—Research fellow in agricultural engineering, University of Minnesota, St. Paul, Minn. (Associate Member to Member)

Reams, Robert E.—Assistant engineer, Allis Chalmers Mfg. Co. (Mail) 2046 S. 8th St., Milwaukee, Wis. (Associate Member to Member)

Snyder, Graydon N.—Agricultural engineer, The Ohio Power Co., 45 S. Monroe St., Tiffin, Ohio (Associate Member to Member)

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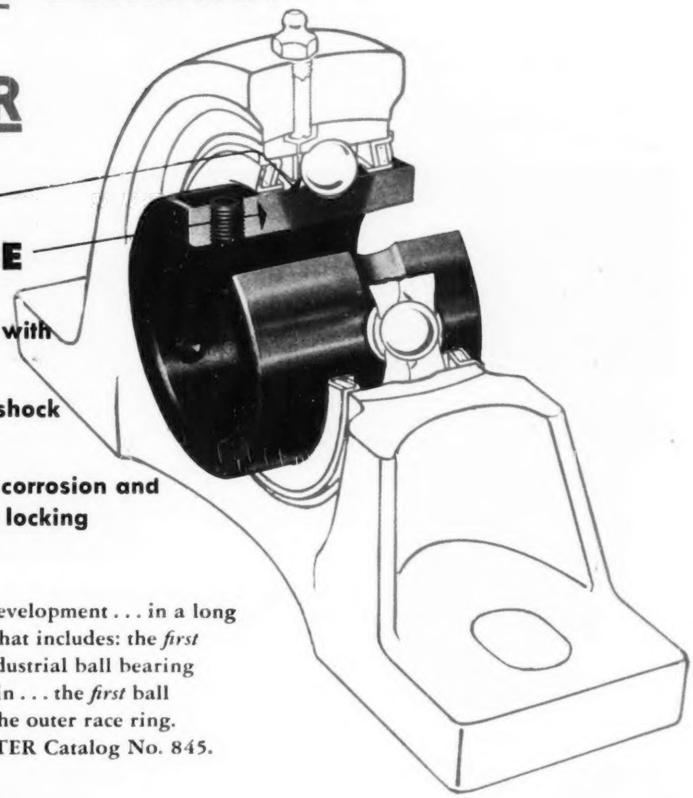


is HARD HERE
but SOFT HERE

- **to permit race-to-shaft locking with increased holding power**
- **to insure greater resistance to shock and vibration**
- **to minimize danger of fretting corrosion and eliminate shaft wear by firmer locking of bearing to shaft**

Zone Hardening is another major development . . . in a long history of SEALMASTER advances that includes: the *first* self-aligning, permanently sealed industrial ball bearing unit . . . the *first* outer race locking pin . . . the *first* ball retainer riding the inner surface of the outer race ring.
Write for your copy of SEALMASTER Catalog No. 845.

ZONE HARDENED
PERMANENTLY SEALED
SELF-ALIGNING • PRE-LUBRICATED
FLOATING BALL RETAINER

***ZONE HARDENING**

is a completely automatic heat treating process by which the inner race ring of SEALMASTER Ball Bearing Units is hardened through ball path section *only*. (See cutaway view.) The extended part of the inner race is left in its original metallurgically soft, tough state. Hardened set screws are mounted through this soft portion, to provide firm race-to-shaft locking and the performance advantages mentioned above. ZONE HARDENING is patented—exclusively SEALMASTER'S!

SEALMASTER BEARINGS

A Division of Stephens-Adamson Mfg. Company
67 Ridgeway Avenue, Aurora, Illinois

PERSONNEL SERVICE BULLETIN

NOTE: In this bulletin the following listings still current and previously reported are not repeated in detail; for further information see the issue of AGRICULTURAL ENGINEERING indicated.

POSITIONS OPEN—JUNE—O-147-524. JULY—O-255-527. SEPTEMBER—O-301-530. OCTOBER—O-348-534, 344-536, 361-537. NOVEMBER — O-341-538, 387-539, 384-540, 399-541. DECEMBER—0-430-542, 454-544, 465-545, 471-546, 479-547, 462-548.

POSITIONS WANTED—MAY—W-193-31, 196-32. JUNE—W-204-34, 200-36, 203-37, 220-40. JULY —W-260-42. AUGUST—W-248-45, 272-46, 278-49, 292-50. SEPTEMBER—W-306-53, 321-54, 339-56. OCTOBER — 333-57, 357-58, 359-59. NOVEMBER—W-329-60, 351-61, 356-62, 368-63, 367-64, 388-65, 369-66, 391-67, 381-69, 378-71, 398-72, 350-73, 404-74, 426-75. DECEMBER—W-395-76, 410-77, 431-78, 396-79, 405-80, 425-81, 420-82, 443-83, 423-84, 453-85, 441-86, 451-87.

NEW POSITIONS OPEN

AGRICULTURAL ENGINEERS (3) for work with the department of agriculture of a government in Africa. Work will include management of machines and mechanized crop production projects, training of native operators, research, and advisory service to individual farmers. BS deg in agricultural engineering, or equivalent. Single men preferred. Age 27-33. Appointment on contract for indefinite period, terminable on 6 mo notice—by either party. Liberal passage and leave provisions. Salary to £1600 per year, payable partly in dollars. Cost of living bonus. Application forms and further details on request. O-488-549

DRAFTSMAN, for design work with manufacturer of farm equipment. Location in Pennsylvania. Age 21-45. Mechanical drafting experience desirable. Want steady man willing to live in city of about 17,000. Head of small department will oversee and direct closely. Good chance to learn. Pay $1.50 to $1.75 per hour at start. O-491-550

AGRICULTURAL ENGINEER (agricultural market specialist) to promote use of various steels in agricultural equipment, through research projects, group contacts, and editing reports and bulletins. Midwest. BS deg in agricultural engineering or equivalent, with major in power and machinery. Age about 25. Intelligent, pleasing personality. Able to write well and speak before technical and trade groups; to supervise and coordinate research; to see and promote new possibilities. Excellent opportunity for young man who likes technical promotional work and has potential for development in that field. Starting salary $375 per mo O-494-551

AGRICULTURAL ENGINEER to teach rural electrification and farm structures in a state university in the South. MS deg preferred. Some field experience desired. Usual personal qualifications for college teaching. Opening effective July 1 or sooner. Salary open. O-508-552

NEW POSITIONS WANTED

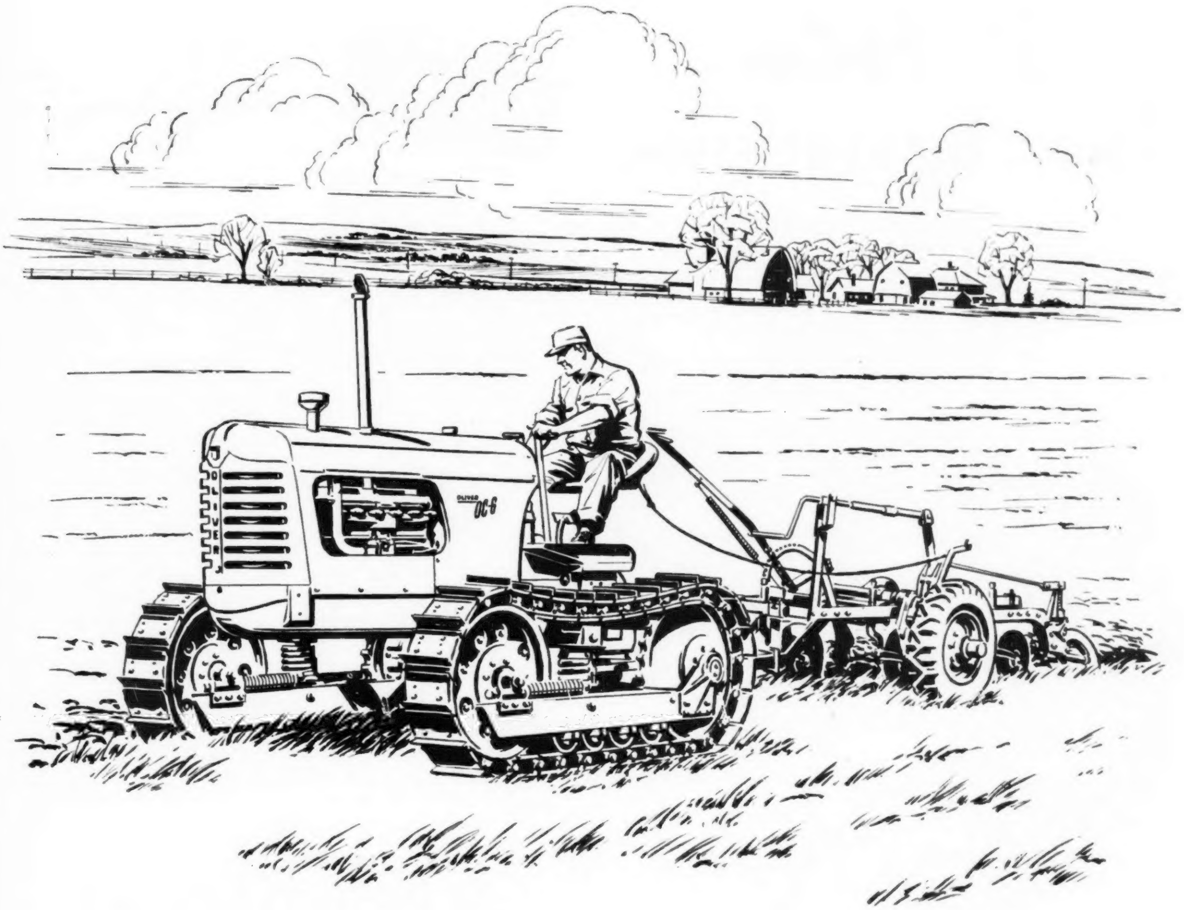
AGRICULTURAL ENGINEER for design, development, research, or writing in power and machinery or product processing field with manufacturer or processor preferably in Pacific Coast area. Married. Age 27. No disability. BS deg with agricultural engineering option, University of California, 1951. Experience as chairman (engineering aide) 2 mo; junior assistant engineer on ships 5 mo; engineering detailer 2 mo. Commissioned service in US Navy 2 yr, 1951-53. Available now. Salary $4800. W-456-88

AGRICULTURAL ENGINEER for creative mechanical engineering in design, development, and research in farm equipment field, with manufacturer. Some preference for central Northeast location. Married. Age 25. No disability. BS deg in mechanical engineering, 1951; MS deg in agricultural and mechanical engineering expected February 1954, Cornell University. Farm background. Test engineer with General Electric Co. two summers. Field testing, drafting, layout, and design with farm equipment manufacturer, 15 mo. Graduate teaching assistant in farm power and machinery, 2 terms. Cornell Aeronautical Laboratory in work on automobile dynamics, 3 mo. Available Feb. 8. Salary open. W-487-89

AGRICULTURAL ENGINEER interested in application of engineering to agricultural production or processing problems. Desire position with consultant, farming operation, processor, manufacturer, distributor, or contractor where there is opportunity for advancement based on ability and initiative. BS deg in agricultural engineering. Three years agricultural extension engineering work interrupted by recall to active duty with the U.S. Navy. Commercial farm background with business and sales experience. Five years commissioned service U.S. Navy. Executive and administrative experience. Skilled in crafts related to engineering. Able to work well with others. Age 33. Married. No disability. Available about January 1. Salary open. W-490-90

AGRICULTURAL ENGINEER, experimental director and writer desires to get into sales promotion or sales and service management in the field of rural electrification. Have plan that will be very valuable to the proper organization in this particular field. Prefer working in the Western States. BS and MS deg in agricultural engineering, 1940 and 1950, respectively. Five years commissioned service with U.S. Air Force during World War II. Five years with electric utility company part of which was as a rural electric agricultural engineer. Six and one-half years in rural electric experimental development and writing with land grant college. Also ¼-time teaching rural electrification classes during this time. Have written and published over thirty publications in field of rural electrification. Licensed professional agricultural engineer. Eighteen years farm background. Married. Age 38. No disability. Available on reasonable notice. Salary $10,000. W-484-91

AGRICULTURAL ENGINEER for design development, research, extension, or teaching in rural electric or soil and water field with industry or public service in Midwest or South. Single. Age 28. Slight disability. BS deg in agricultural engineering, 1952, South Dakota State College. Farm background, including 2 yr farm experience after high school. Enlisted service in Infantry and Army Service Forces (finance). In present position, construction engineer on 115 KV transmission lines and substations, Bureau of Reclamation, 20 mo. Available on reasonable notice. Salary open. W-418-92



Everything . . . on tracks!

In this all-new, 3-plow Oliver "OC-6" crawler is every significant farm power feature a farmer wants! Plus two great advantages—*extra* traction and flotation.

First of all, there's a choice of two smooth, 6-cylinder overhead valve engines—diesel or gasoline. Added to that are six forward speeds, an *independently controlled* power take-off, convenient hydraulic control system, comfortable rubber torsion spring seat and a three-point hitch with tool bar attachments.

Here's a tractor that converts *more* engine power into pulling power, that goes anywhere in any weather. Yet, it "floats" over sand and muck, leaving track marks shallower than your footprints!

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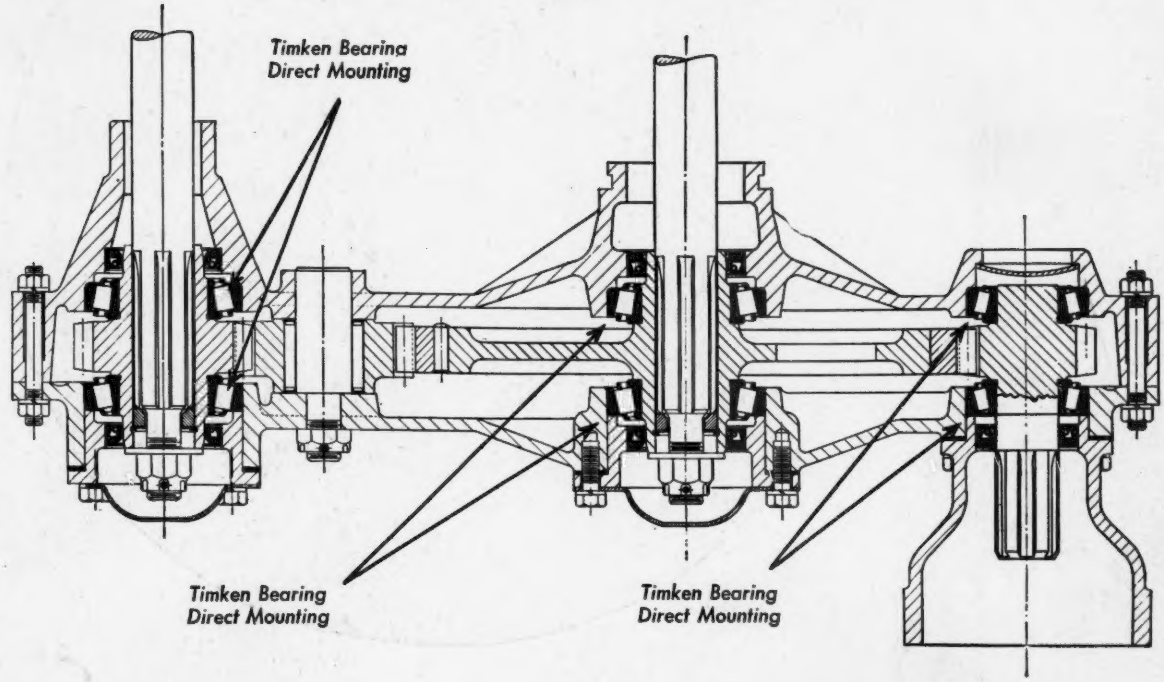
Index to Advertisers

How Allis-Chalmers Maintains Accurate Gear Mesh in the New Roto-Baler



WHEN Allis-Chalmers engineers designed the new Roto-Baler they had the problem of keeping the gears in alignment and in accurate mesh. Here's how Timken® tapered roller bearings helped them solve it.

Each shaft has a direct Timken bearing mounting. The shafts are held in positive alignment because Timken bearings prevent movement in any direction, radially or laterally. The tapered design enables the bearing to take *both* radial and thrust loads in any combination. The gears mesh accurately and operating in a bath of oil the gear wear is negligible.

Timken bearings help farm equipment engineers solve another big problem: closures. Because of their close tolerances, Timken bearings hold shafts and housings concentric. This makes the bearing seal more effective. Lubricant is held in; dirt, dust, mud and moisture are kept out.

Timken bearings reduce friction to a minimum, make the Roto-Baler operate more smoothly. They have an *incredibly* smooth surface finish. And they have *true rolling motion* because lines drawn coincident with the working surfaces of the rollers and races will all meet at a common point on the axis of the bearing.

Timken bearings help you solve three big design problems: dirt, combination loads, ease of operation. Write now for your free copy of our helpful, informative booklet, "Tapered Roller Bearing Practice in Current Farm Machinery Applications". The Timken Roller Bearing Company, Canton 6, Ohio. Cable address: "TIMROSCO".

The farmer's assurance of better design

NOT JUST A BALL NOT JUST A ROLLER THE TIMKEN TAPERED ROLLER BEARING TAKES RADIAL AND THRUST LOADS OR ANY COMBINATION